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Energy resources in 2050

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Abstract of master thesis

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Abstract

The scarcity of energy from fossil fuels has led to future concerns about energy adequacy. New long-term energy investment strategies are needed to reduce the dependence on fossil fuels and to achieve long-term targets for reducing CO2 emissions. Several countries are developing new energy sustainability strategies that meet the growing energy needs by changing the way energy is produced and used. Therefore, legislative measures and directives are being taken to secure these energy strategies. For instance, many countries are, or are considering, replacing old coal-fired plants with renewable energy sources.

The purpose of this thesis is to analyse the rise of energy demand and how energy challenges will be overcome in the future throughout policies, laws, directives and incentives. In other words, the answer to how to produce and deliver secure, sustainable and affordable energy without compromising decarbonisation goals. Moreover, as fossil fuel power plants are slowly being decommissioned, a wider range of energy-generating mix is required. In practice, this means that reaching emission reduction targets require rapid increase in overall energy efficiency as well as in renewables, such as, solar and wind production technologies. On the other hand, the increase of variable renewables has led to new challenges in the electricity markets. Namely, large hourly fluctuations in the production capacity causes encumbrance on the electricity grid. As energy systems will be more complex and require more interaction, new energy technologies are needed with smarter grids and transmission networks.

Keywords renewable energy, energy resources, fossil fuels, nuclear energy, electricity generation, energy scenarios

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Sammandrag

Naturresursernas knapphet angående fossila bränslen har lett till allmän oro för framtidens energitillgänglighet. Nya och långsiktiga investeringar inom energibranschen är nödvändiga för att minska beroendet av fossila bränslen samt för att uppnå de långsiktiga målen för minskning av koldioxidutsläppen. Nya hållbara strategier angående energiproduktionen och förbrukningen upptäcks av olika länder för att kunna möta stigande energibehovet. Därmed fattas lagstiftningsåtgärder och direktiv för att skydda de ovannämnda strategierna angående energin. Till exempel, flera länder ersätter redan nu eller kommer att ersätta de gamla kolkraftverken med förnybara energikällor.

Syftet med detta arbete är att analysera ökningen av energiefterfrågan samt hur framtidens utmaningar angående energin kommer att övervinnas med hjälp av politik, lagar, direktiv och incitament. Med andra ord, svara på frågan hur man kommer att producera och leverera säker, hållbar och rimligt prissatt energi utan att riskera målen för minskningen av koldioxidutsläppen. Ytterligare är det nödvändigt att skapa ett större utbud av olika energimix för att de föråldrade fossila kraftverken kommer långsamt att avvecklas inom framtiden. I praktiken innebär detta att uppnåendet av målen för minskningen av utsläppen kräver en snabb ökning av den totala energieffektiviteten såväl som i förnybara energikällor, till exempel sol- och vindkraft. Å andra sidan leder ökningen av varierande förnybara energikällor till nya utmaningar på elmarknaderna. Stora fluktuationer inom elproduktionen orsakar nämligen hinder på elnätet. Eftersom energisystem kommer att vara mer komplexa och kräver mer interaktion krävs ny energiteknik med smartare nät och kraftledning inom elöverföringen.

Nyckelord förnybara energikällor, energiresurser, fossila bränslen, kärnkraft, elproduktion, energiscenarier

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Tiivistelmä

Fossiilisten polttoaineiden energian niukkuus on johtanut tulevaisuuden huolenaiheisiin energian riittävyydestä. Pitkän aikavälin uudet investointistrategiat ovat tarpeen fossiilisten polttoaineiden riippuvuuden vähentämiseksi ja pitkän aikavälin tavoitteiden hiilidioksidipäästöjen vähentämisen saavuttamiseksi. Useat maat muodostavat uusia strategioita kestävän energiatalouden puolesta, mitkä tulisivat vastaamaan kasvaviin energian tarpeisiin muuttamalla energian tuotantotapaa ja käyttöä. Näin ollen energiatalouden investointistrategioiden turvaamiseksi toteutetaan lainsäädännöllisiä toimenpiteitä ja direktiivejä, esimerkiksi monet maat korvaavat tai harkitsevat vanhojen hiilivoimalaitosten korvaamista uusiutuvilla energialähteillä.

Tämän työn tarkoituksena on analysoida energian kysynnän nousua ja sitä, miten energiahaasteet selvitetään tulevaisuudessa uusien linjausten, lakien, direktiivien ja kannustimien avulla. Toisin sanoen, työssä vastataan siihen, kuinka tuottaa ja toimittaa turvallista, kestävää sekä kohtuuhintaista energiaa vaarantamatta hiilidioksidipäästöjä vähentämistä koskevia tavoitteita. Lisäksi, fossiilisten polttoaineiden voimalaitokset ovat hitaasti poistumassa käytöstä, jonka johdosta tarvitaan laajempi valikoima energialähteistä. Käytännössä tämä tarkoittaa sitä, että tavoitteet päästöjen vähentämisestä vaatii nopeaa energiatehokkuuden ja uusiutuvien energialähteiden, kuten aurinko- ja tuulivoimatekniikan kasvua. Toisaalta uusiutuvien energialähteiden lisääntyminen johtaa uusiin haasteisiin sähkömarkkinoilla, nimittäin tuotantokapasiteetin suuret vaihtelut aiheuttavat rasitusta sähköverkolle. Näin ollen tulevaisuudessa energiajärjestelmät ovat monimutkaisempia sekä vaativat enemmän vuorovaikutusta, mikä edellyttää kehittämistä älykkäämpien verkkojen sekä sähkönsiirron kanssa.

Avainsanat uusiutuva energia, energialähteet, fossiiliset polttoaineet, ydinvoima, sähköntuotanto, energiaskenaariot

Preface

I want to thank my supervisor and instructor Professor Matti Lehtonen for introducing me to this topic. I would also like to thank him for all the guidance and counselling throughout this thesis process.

Finally, I would like to thank my family for all the support related to the writing of this thesis.

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Kennet Bexar

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Units of Measure

bcm	billion cubic metres
CO_2	carbon dioxide
EJ	exajoule
GW	gigawatt
GWe	gigawatt electrical
L	litre
mb/d	millions of barrels per day
Mt	million tonnes
Mtoe	million tonnes of oil equivalent
MW	megawatt
TWh	terawatt hour
W	watt

Abbreviations

CAAGR	compound average annual growth rate
CAFÉ	corporate average fuel economy
CCS	carbon capture & storage
CEER	Council of European Energy Regulators
DH	district heating
ETS	emissions trading scheme
EU	European Union
FIT	feed-in tariff
GDP	gross domestic production
GHG	greenhouse gas
HVO	hydrotreated vegetable oil
IEA	International Energy Agency
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of Petroleum Exporting Countries
PPA	power purchase agreement
PV	photovoltaics
REPS	Renewable Energy Portfolio Standard
RES	renewable energy resource
RFS	renewable fuel standard
SET	strategic energy technology
TPES	total primary energy supply
UK	United Kingdom
USA	United States of America
VRE	variable renewable electricity
WEO	World Energy Outlook

1 Introduction

Growing energy needs and the use of non-renewable fossil fuels as a source of primary energy have led to increased future concerns about energy sustainability. Moreover, increasing global temperatures and greenhouse gas (GHG) emissions have resulted in an interest in renewable technologies and decarbonisation of the energy production. Namely, several member states of UN and international energy agencies have implemented new policies and guidelines to counter global climate change and to increase the energy sustainability as well as to decrease the dependency on fossil fuels. For instance, the well-known international treaty, that is, the 1997 Kyoto Protocol that focused on the environmental impacts of energy use and the effects of the increased GHG emissions, which led to an agreement of broad outlines of emissions targets, such as, to reduce the fossil-fuel consumption and CO_2 emissions. Another example of an energy policy is within the European Union the 20-20-20 target, which include that 20 % of energy production should be directly from renewables, energy efficiency should be increased by 20 % and greenhouse-gas emissions should be reduced by 20 % by the end of the year 2020. Third example is the Paris Agreement, in which several nations agreed to combat climate change by keeping the global temperature rise in this century under 2 degrees Celsius. As a result, the share of renewable energy sources (RES) has increased globally, as has the awareness of increasing carbon emissions.

New policies and plans from governments are intended to guarantee energy availability and that they can be easily obtained in a sustainable way in the coming years. Therefore, the future projection of energy use in 2050 will be considerably dependent on both present and future guidelines, policies, international agreements and treaties. Moreover, technological advancement must also be taken into account in the projection. In other words, it can be expected that energy efficiency for current energy harvesting technologies will rise in the future, as well, there will be more alternative and compensatory techniques to replace outdated and less energy efficient technologies.

This thesis will focus on projection the future energy outlook for the year 2050. The aim of the thesis is research and study the past and present energy policies in order to get a better understanding for the future projection. This thesis is divided in the following way:

Chapter 2 discusses current energy resource trends with its current and future projections. Chapter 3 presents past and present international treaties as well as different regional governmental policies that affect the energy sustainability and strategies. Finally, Chapter 4 discusses different energy resource trends and developments toward 2050. Different scenarios of energy trends are presented from various literature and analysed.

2 Recent Energy Trends

In order to have a better understanding of what the energy outlook for 2050 looks like, it is necessary to look at the increase and decrease in the use of different energy sources in previous years. The International Energy Agency (IEA) has published a comprehensive annual document, World Energy Outlook (WEO), since 1977. WEO provides extensive insight and analysis on energy developments in terms of energy demand and supply. WEO discusses different scenarios, which have affected the energy use and policies for each year for different countries and regions. WEO also provides valuable information on how energy politics and practices have evolved in previous years to date. This chapter will discuss the most common energy sources, their use and development, and how they are used by different countries and regions. In addition, the importance of energy efficiency and concerns about future grid integration will be discussed.

2.1 Renewable Energy Sources

The share of renewables has steadily increased globally each year and future projections include large rises in both photovoltaics (PV) and wind turbines. For instance, European Union has set ambitious goals amongst its member states regarding renewables. In particular, the European Green Deal roadmap, which aims to be the first climate neutral continent [1], more on this in Chapter 3. On the other hand, in Asia, The People's Republic of China (China) has made significant investments in solar energy and wind power and it is estimated that renewables expansion will be largest in China [2, p. 15].

In 1973, the total primary energy supply (TPES) by fuel of geothermal, solar, wind, tide/wave/ocean and heat were only 0.2 %, whereas in 2016 the fuel shares of TPES were 2.2 % [3, p. 7]. The rise of renewables can be explained by overall increase in energy demand as well as energy independence, which in return have led countries to make plans and strategies to increase energy sustainability and availability. In fact, it is estimated that renewable electricity generation is going to be the fastest growing regarding electricity with an increase from 25% to 30% between 2018-2024 [2, p. 24]. The renewable electricity growth is depicted in Figure 2.1. Tables 2.1 and 2.2 present the forecasted data for total renewable electricity capacity by technology and total renewable electricity generation by technology for the years 2018-2024, respectively. The accelerated case in Table

2.1 refers to a faster renewable capacity growth, namely 26% increase if governments overcome three challenges: 1) policy and regulatory uncertainty; 2) high investment risks in developing countries; and 3) system integration of wind and solar in some countries.

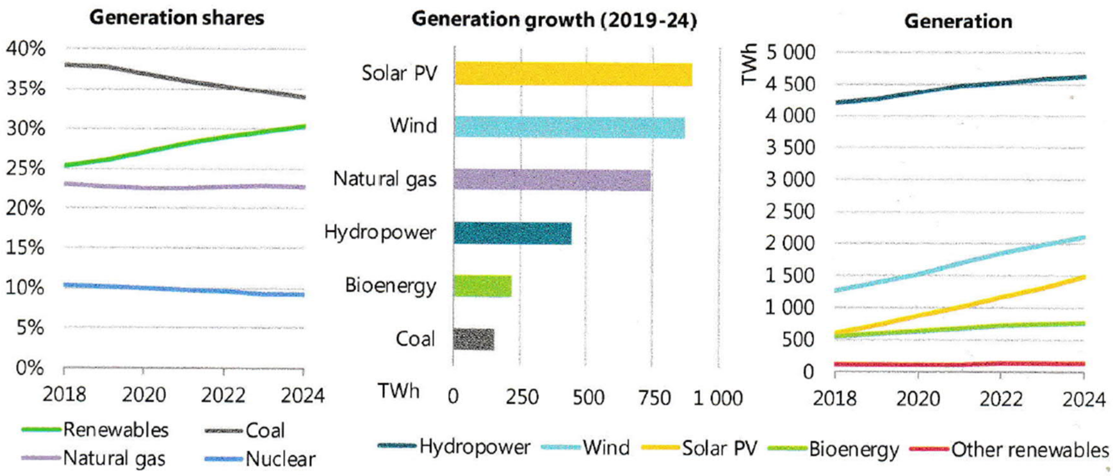

Figure 2.1 – Global generation shares by fuel, and growth by renewable technology, 2019-2024. [2, p. 24]

Table 2.1 – Total renewable electricity capacity by technology (GW). [2, p. 192]

	Main case							Acc. case
	2018	2024	2020	2021	2022	2023	2024	2024
Hydropower	1 290	1 308	1 337	1 357	1 373	1 394	1 411	1 447
Pumped storage	155	158	163	167	171	176	181	202
Bioenergy	130	138	146	152	159	165	171	187
Wind	565	622	686	744	799	857	917	996
Onshore wind	543	595	654	704	753	802	851	920
Offshore wind	22	27	32	39	46	55	66	77
Solar PV	496	609	716	823	939	1 064	1 195	1 374
PV - Utility	283	352	411	469	532	598	665	754
PV - Distributed	213	258	305	354	407	466	530	619
CSP	6	6	7	8	9	9	9	12
Geothermal	14	15	15	16	17	18	18	20
Marine	1	1	1	1	1	1	1	1
Total	2 501	2 699	2 907	3 101	3 296	3 508	3 721	4 036

Table 2.2 – Total renewable electricity generation by technology (TWh). Note CAAGR = compound average annual growth rate. [2, p. 192]

	2018e	2019	2020	2021	2022	2023	2024	CAAGR
Hydropower	4 203	4 258	4 385	4 483	4 537	4 591	4 648	2%
Pumped storage	115	125	129	134	139	144	149	4%
Bioenergy	546	599	640	683	715	746	761	6%
Wind	1 268	1 389	1 534	1 698	1 852	1 998	2 135	9%
Onshore wind	1 202	1 307	1 433	1 571	1 697	1 808	1 921	8%
Offshore wind	66	82	101	126	155	190	214	22%
Solar PV	585	720	864	1 005	1 151	1 309	1 480	17%
CSP	13	16	18	20	25	26	26	12%
Geothermal	90	94	98	101	106	111	116	4%
Marine	1	1	1	1	1	1	1	3%
Total	6 707	7 076	7 542	7 991	8 387	8 783	9 168	5%

2.1.1 Solar Energy

Solar energy is harvested mainly by photovoltaics, solar thermal collectors, and concentrating solar collectors. Solar energy is a clean source of energy, since the sun provides limitless energy and fuel is not required after the installation of PVs. The share of solar PV electricity production has risen significantly in the 21st century. In 2005, the solar PV electricity production was 4 TWh, and in 2015 the shares had risen to 247 TWh [3, p. 24]. The difference is significant, which is to a great extent constituted by the rise of investments from China in the PV market. Namely, the total share of China's PV electricity production has risen from 2.1 % to 18.3 % between 2005-2015, this has led to China being the one of the largest PV electricity producers in 2015 with a 45 TWh production and a net installed capacity of 43.2 GW. [3, p .25]. However, Europe has still the largest distributed PV capacity worldwide, followed by China, Asia-Pacific and North America, which is shown in Figure 2.2. The high share of PVs in these regions can be explained by favourable policies and incentives regarding PVs.

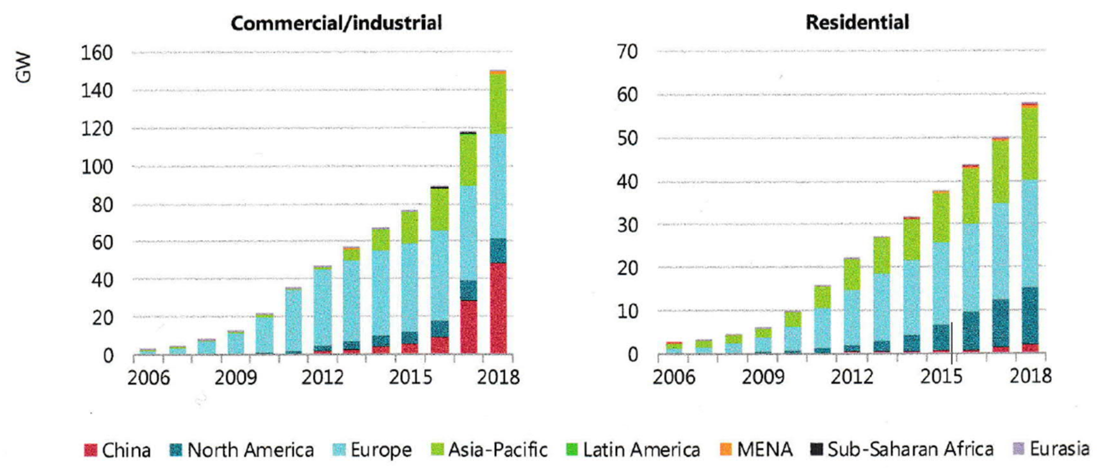

Figure 2.2 – Commercial/industrial and residential solar PV capacity by country/region. [2, p. 70]

There is a clear trend for PVs and other solar energy harvesting methods, which can be expected to rise in the near future. In addition, technological advancements, such as more suitable material, can significantly improve the efficiency of PVs, which in turn can make PVs more adequate. Namely, 60-80% decreased investment costs in distributed solar PV deployment since 2010 have increased the interest of investors [2, p. 66]. Figure 2.3 shows how investment costs have reduced since 2010.

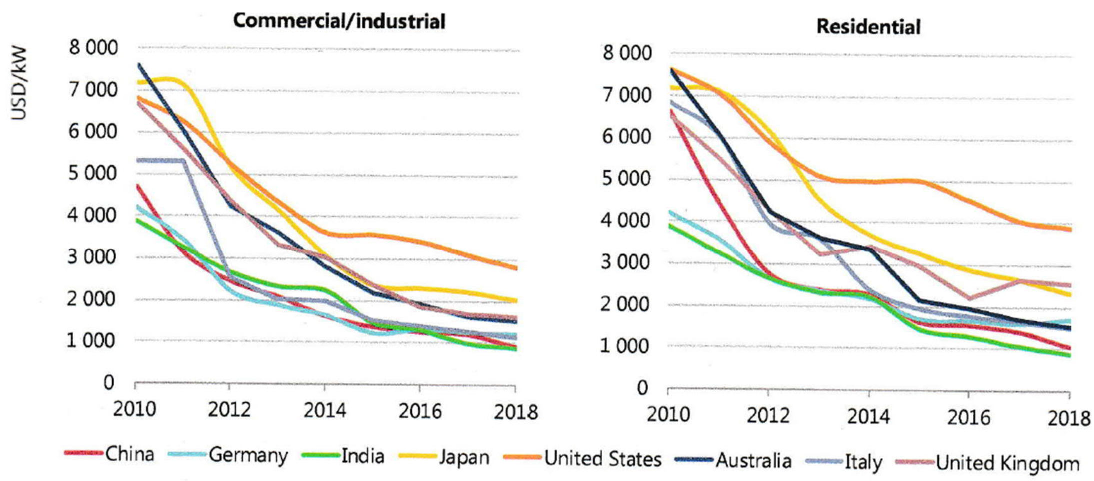

Figure 2.3 – Investment costs for commercial/industrial and residential systems in selected countries. [2, p. 71]

2.1.2 Wind Power

Wind power or wind energy is harvested with wind turbines, either onshore or offshore, which are connected to the electricity power transmission network. Wind power enables electricity generation without the use of fossil fuels and without causing greenhouse gas emissions and other pollutants. As with PVs, wind power costs are estimated to decrease due to material costs reductions and the efficiency of wind turbines in the harvesting of wind are expected to increase. Public acceptance plays an important role in wind farm design, namely, visual appearance and noise pollution caused by wind turbines affect building permits of wind farms.

Solar is not the only renewable energy source which has seen a market bloom, namely, wind power production has increased notably from 2005 to 2015. In 2005, the total wind power share of electricity production was 104 TWh, whereas in 2015 the shares had risen to 838 TWh [3, p. 22]. Figure 2.4 represents the increase in wind electricity production. As in solar energy, wind power rise can be explained by the investments done by China, which had the largest net installed capacity of 129.3 GW in 2015 [3, p.23]. In addition, China was also the second largest producers of wind power in 2015 with a 186 TWh production accounting for 22.2 % of total world production, compared to only 2.0% in 2005 [3, p. 23].

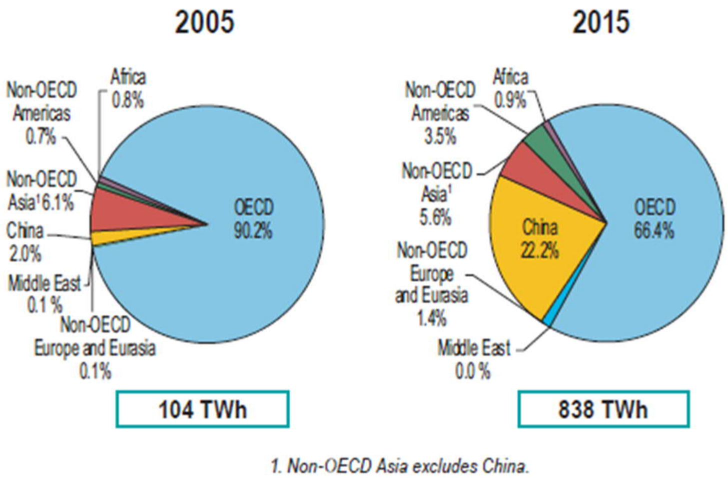

Figure 2.4 – 2005 and 2015 regional shares of wind electricity production. [3, p. 22]

2.1.3 Geothermal Energy

The energy which can be obtained from the crust of the earth either by as hot water or steam is referred to as geothermal energy. The heat energy within the earth's crust is usually stored in rocks, vapour, water and brines, which can then be used directly for district heating, cooling or for electricity generation. The energy is obtained by drilling steam or water wells, where the water or steam is transported to the surface, after which it is converted to electricity, for instance, through generators. Geothermal energy provides a sustainable and a reliable production of energy, since climatic fluctuations do not affect geothermal power plants. Moreover, geothermal energy provides a vast resource with constant availability.

In 2017, the global geothermal energy capacity was in total 14.3 GWe, with the largest capacity in the United States of America (USA) followed by Philippines, Indonesia, Turkey and New Zealand. Figure 2.5 shows the worldwide installed geothermal capacity in 2017. Geothermal energy in its current state is limited to a few countries, thus, its contribution is relatively small compared to other renewables. However, regarding district heating and cooling, in Europe it is estimated that geothermal consumption is going to increase by 270% during 2019-2024 [2, p. 144].

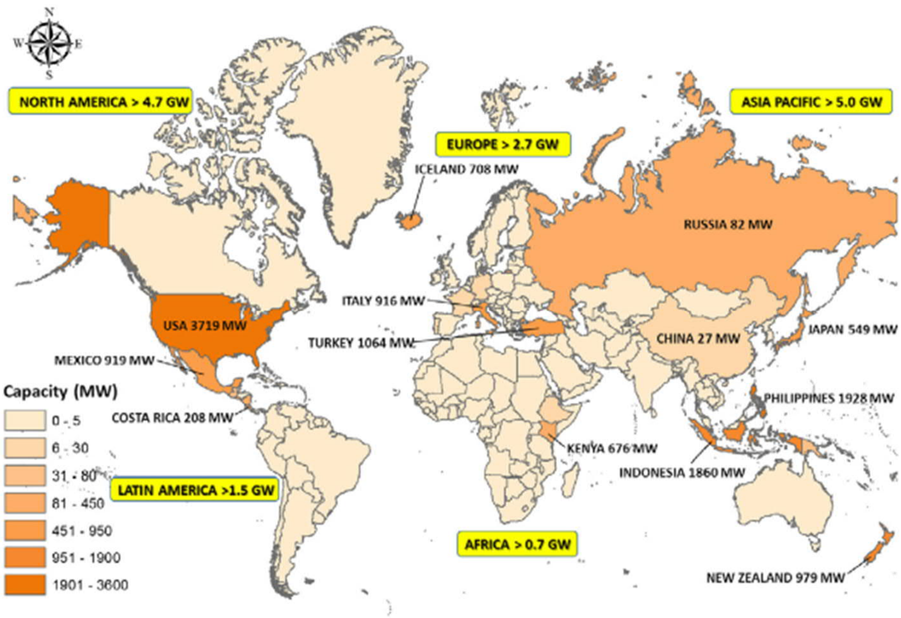

Figure 2.5 – Worldwide installed capacity of geothermal energy in 2017. [5]

2.1.4 Biofuel and Bioenergy

Biofuels and bioenergy are organic, non-fossil biomass, which can be used for electricity generation or heat production. Biofuels and waste include solid and liquid biofuels, biogases, as well as industrial and municipal waste. Bioenergy and biofuels are showing promising results in providing carbon neutral free energy. On the other, they also contend with global food production, since the necessity of allocating arable land for the production of biofuel and bioenergy. Moreover, the production is highly dependent on several factors, such as: corn and sugarcane production, technological constraints, variation of the feedstock prices, logistics, socioeconomic backgrounds, domestic and foreign policies, locational issues, water scarcity, land use restrictions, and cost-effectiveness [6].

First-generation biofuels include but are not limited to ethanol, methanol, hydrotreated vegetable oil (HVO) and biodiesel. First generation biofuels are made from sugar and starch (sugarcane, cereals, cassava, sugar beet etc.) or oilseed (rapeseed, soybean, sunflower, palm oil etc.). The technology with first-generation biofuels is well developed (produced commercially for several years). However, the disadvantageous with first-generation biofuels is that they directly compete with food supply. In other words, the costs of the biofuels are sensitive to feedstock prices and agricultural products. Whereas, advanced or second-generation biofuels do not affect food production, since it can be produced by feedstocks that do not compete with food supply. [7]

Second-generation biofuels are produced from lignocellulosic biomass, that is, non-edible feedstocks (woody crops, agricultural residues or waste). Second generation bioenergy and fuels aim to utilize biomass sources that do not harm biodiversity or affects food production. The increased demand could potentially cause major human right crisis when arable land is allocated to bioenergy production instead of food production, in which, the food production is unable to satisfy the increased demand from growing global population. [7]

In 1973, biofuels and waste accounted for 10.5% of TPES, while in 2015 the share had decreased to 9.7% [3. p. 6]. However, in Organisation for Economic Co-operation and Development (OECD) countries the share of biofuels and waste had increased from 2.3% to 5.7 % in the same period [3, p7.]. The US had in 2016 43.5% of the world total share of biofuel production, followed by Brazil with 22.5%. The growth in OECD countries can be explained by growing policy support towards bioenergy. Regarding renewable heat, bioenergy accounted for over than two-thirds of worldwide renewable heat consumption in 2018. In addition, it is estimated that its use will rise 12% during 2019-2024 [2, p. 129].

With growing fossil fuel prices and higher emission levels, biofuels are a considerable alternative way of replacing incrementally traditional fuels in the transport sector. In [2, p.107], it is estimated that biofuel output is going to increase 25% between 2019-2024, with Brazil, United States (US) and China as frontrunners. Moreover, HVO production is estimated to increase more than double from 5.5 billion L to 13 Billion during 2018-2024 [2, p. 107]. Global biofuel production during 2018-2024 is illustrated in Table 2.3.

Table 2.3 – Global biofuel production. [2, p. 109]

Billion L	2018	2019	2020	2021	2022	2023	2024	Share of production 2024	Share of growth 2019-24
North America	71.0	71.5	72.5	75.5	77.0	77.5	77.5	41%	19%
Latin America	43.0	43.5	44.5	46.5	47.5	49.5	51.5	27%	23%
Europe	20.5	21.0	23.0	22.0	21.5	21.0	21.5	11%	3%
Asia	16.5	19.5	22.0	26.0	30.5	32.0	35.0	20%	53%
Rest of world	1.5	2.0	2.0	2.5	2.5	2.5	2.5	1%	2%
Total	**152.5**	**157.5**	**164.0**	**172.0**	**178.5**	**182.5**	**187.5**	**100%**	**100%**

2.1.5 Hydropower

Hydropower is produced by taking advantage of the potential and kinetic energy of water and using it for electricity generation in hydroelectric plants. Hydropower is one of the oldest renewable electricity sources. Hydropower is increasing gradually, in 1973, the share of TPES was 1.8%, and in 2015, the share had increased to 2.5% [3, p. 6]. Figure 2.6 illustrates the global hydroelectricity production between 1971-2015 in TWh. The increase is the result of China’s large investments in hydroelectricity. In 2015, China’s production alone constituted 1130 TWh, which was 28.4% of world total production [3, p. 21]. Hydropower is expected to grow in future due to its sustainability and huge potentials in non-OECD countries. Moreover, it is estimated that hydropower will remain as world's primary renewable energy power in 2024 with a 9% increase in capacity, that is, an increase of 121 GW during 2019-2024 [2, p. 19].

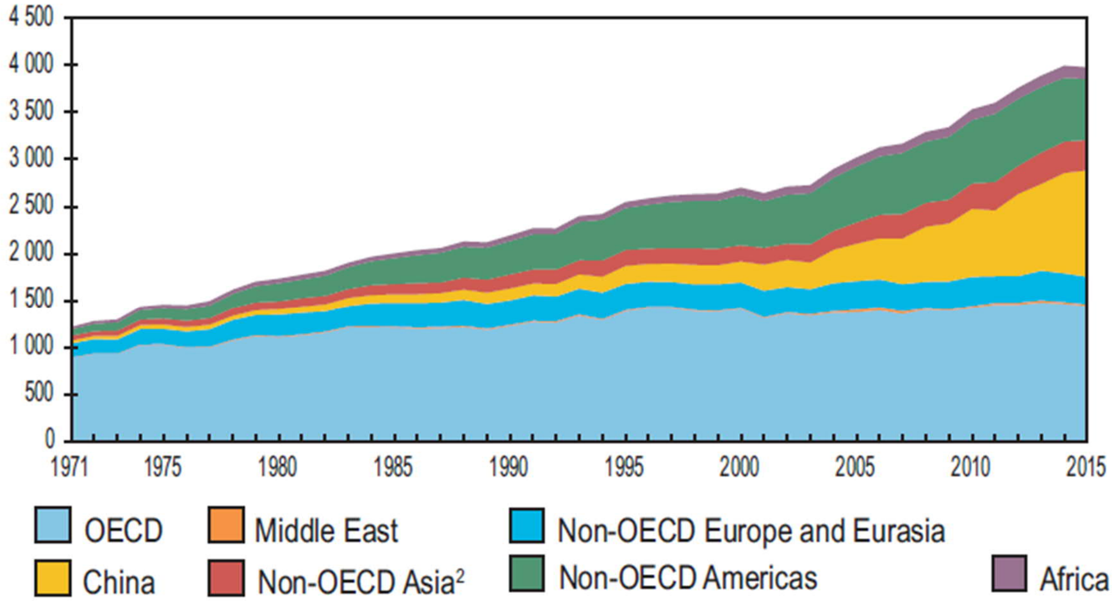

Figure 2.6 – Hydroelectricity production from 1971 to 2015 by region (TWh). [3, p. 20]

Challenges which affect hydropower is the complexity of hydropower projects and lifespan of electro-mechanical parts, such as, batteries, turbines and generators. In addition, continuous maintenance is required, such as replacing hydropower components and repairing equipment. Otherwise, performance, efficiency and output power may decrease [2, p. 158].

2.1.6 Energy Storage

With the growing trend in renewable energy sources, the demand for energy storage has risen correspondingly. Storage technologies also support de-carbonization and energy sustainability. Weather fluctuations regarding renewables are common, therefore it is necessary to control the supply side of electricity production in order to efficiently meet the demand. Further benefits from energy storage include but are not limited to: improved electricity grid stability, resilience, and flexibility; easier energy access; better capabilities to integrate variable renewable energy sources to end-users; and compensate long-term supply disruptions or variabilities in energy production [8]. Energy storage technologies are still in early stages and more development is needed to reach maturity and commercialisation. Moreover, governmental financing and support is needed in order to compete with non-storage technologies, such as, fossil fuels. Usually, the most common conversions regarding energy storage are electricity to heat, heat to electricity, electricity to electricity, and heat to heat. It is estimated that a total demand of 400 GW by 2050 is needed regarding energy storage in consequence of an increase of variable renewables [9].

2.2 Fossil Fuels

This subchapter discusses the current role and roadmap for fossil fuels. The primary fossil fuels consist of natural gas, coal, oil, peat and oil shale, which are used in several sectors, such as, power, industry, transport, agriculture, and building. The share of fossil fuels of TPES in 1973 were 86.7%, whereas in 2015 the shares had decreased to 81.4% [3, pp. 6-7]. The decrease can be explained by the rise of nuclear power and renewables. However, the large use of fossil fuels and their contribution to climate change have shifted the opinion and public acceptance of their use. With the support of international agreements and directives, as well as policies of several governments, it has resulted in incremental phase-out of fossil fuel power plants and decommissioning of old fossil fuel-based industries.

2.2.1 Natural Gas

Natural gas use has steadily increased and the projected growth rate is expected to be faster compared to coal and oil in future. The reason lies in the governmental policies, which favour and encourage gas over coal because of less environmental pollutants and greenhouse gas emissions. The cost and price of natural gas affect the long-term projections of its usage. Currently, there is no specific global price for gas, in other words, the gas price is dependent on regional prices. However, it is expected in the future that regional gas prices will be more interlinked due to increased share of liquefied natural gas, which improves the flexibility of the global trade. [4]

The share of natural gas of TPES has risen since 1973 from 16% to 21.6% in 2015 [3, p.6]. The three largest producers are the US, Russia, and Iran, which accounted for 43.8% of the world production in 2016 [3, p. 14]. In Figure 2.7 the natural gas production is shown by region from 1971 to 2016.

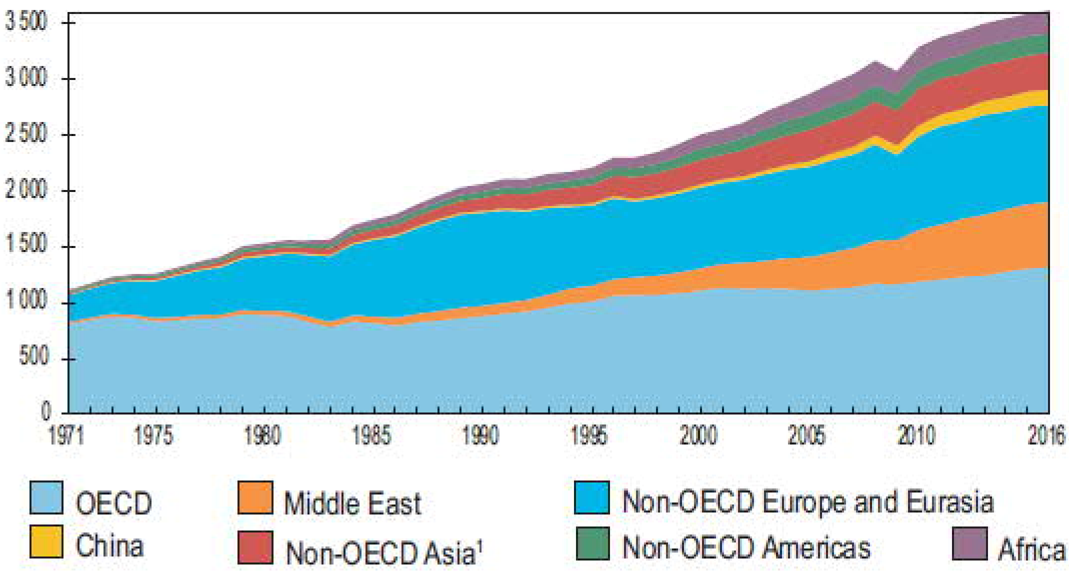

Figure 2.7 – World natural gas production from 1971 to 2016 by region (bcm). [3, p. 14]

2.2.2 Coal

The share of coal of TPES has increased from 24.5% to 28.1% between years 1973-2015 [3, p. 6]. However, projections and estimates show that coal will eventually reduce its share in the energy usage. For example, new guidelines and plans for several countries include the phase-out of coal-fired power entirely, for instance, France by 2023, the United Kingdom (UK) by 2025 and Finland by 2030. Moreover, Germany that is heavily coal reliant with 50 GW coal capacity is undergoing phase-out discussions. [10]

Nonetheless, the impact of phase-outs will not necessarily have large effects regarding climate aspects, if larger coal users, such as China, India and the US, will not reduce their dependence on coal. Evidently, transition to lower carbon power systems is required by replacing low-efficient coal-fired technologies with low emission and high-efficiency techniques. As with natural gas, coal use will be affected by the availability and price of coal, which is not bound to a global price, instead it is dependent on a regional coal market price. Figure 2.8 shows regional shares of coal production for 1973 and 2016 in million tonnes (Mt).

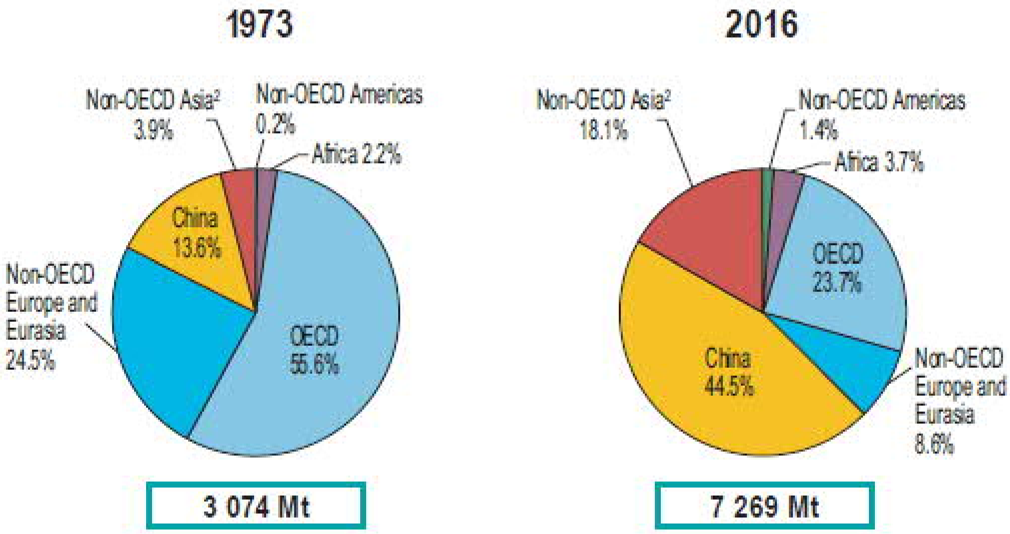

Figure 2.8 – Coal demand, production and trade by scenario (Mt). [3, p. 16]

2.2.3 Oil

Oil share of TPES has largely decreased from 1973 to 2015, in other words, from 46.2% to 31.7% [3, p. 6]. Oil is consumed mainly on transportation, non-energy use (e.g. raw materials), industries, aviation, navigation, residential, and agriculture. Currently, the largest oil consumers are the US, China and India, and in 2015 they alone net imported in total 884 Mt of oil [3, p. 13].

Oil prices are driven by global prices, which can be affected by different types of scenarios, such as the 1970 oil crisis or the financial crisis that began in 2008, with oil prices increasing dramatically in both scenarios. Moreover, oil price is influenced largely by the Organization of Petroleum Exporting Countries (OPEC), which controls roughly 40% of the oil supply of the world. Moreover, oil is a limited natural resource and its demand growth is limited by governmental policies and international agreements. In Table 2.4 oil producers, net exporters and net importers are presented for year 2015.

Table 2.4 – World oil producers, net exporters and net importers in 2015. [3, p. 13]

Producers	Mt	% of world total
Saudi Arabia	583	13.5
Russian Federation	546	12.6
United States	537	12.4
Canada	220	5.1
Islamic Rep. of Iran	200	4.6
People's Rep. of China	200	4.6
Iraq	191	4.4
United Arab Emirates	182	4.2
Kuwait	159	3.7
Brazil	135	3.1
Rest of the world	1 368	31.8
World	**4 321**	**100.0**

Net exporters	Mt
Saudi Arabia	369
Russian Federation	243
Iraq	148
United Arab Emirates	125
Canada	116
Nigeria	104
Kuwait	100
Venezuela	98
Angola	86
Islamic Rep. of Iran	64
Others	539
Total	**1 992**

Net importers	Mt
United States	348
People's Rep. of China	333
India	203
Japan	165
Korea	139
Germany	91
Italy	67
Spain	65
Netherlands	59
France	57
Others	514
Total	**2 041**

2.3 Nuclear power

The use of nuclear power increased from 0.9% of world TPES to 4.9% between 1973 and 2015 [3, p. 6]. Currently, OECD countries are the largest nuclear electricity producers. In 2015, the regional shares of OECD countries regarding nuclear electricity production was 76.7% [3, p.18]. The US, France and Japan have the largest net installed capacities, that is, 99, 63 and 40 GW respectively [3, p.18].

Nuclear power has had controversial discussion, concerns and several challenges due to its public appearance. The main reason behind the controversy are the well-known tragic disasters concerning nuclear power, that is, the Chernobyl disaster in 1986 and Fukushima in 2011. This has raised the question to whether pursue or phase out nuclear power in the public, while nuclear power has low carbon-dioxide emissions its major concerns are related to nuclear plant safety, nuclear weapons proliferation and the management of long-term radioactive waste disposal. In result, it is expected that nuclear power and its growth rate will slow down compared to its past growth. Governmental policies and shifting public opinions and local acceptance have key role whether investments regarding nuclear plants are facilitated or not.

Figure 2.9 forecasts how nuclear energy growth will fluctuate between 1980-2040. From the figure it can be noted that within the OECD nuclear energy output will decrease, this is explained by the fact that aging nuclear plants are decommissioned and there will be a limited amount of investments in new nuclear capacity [11]. Whereas, in China nuclear energy will rise steadily with 1000 TWh.

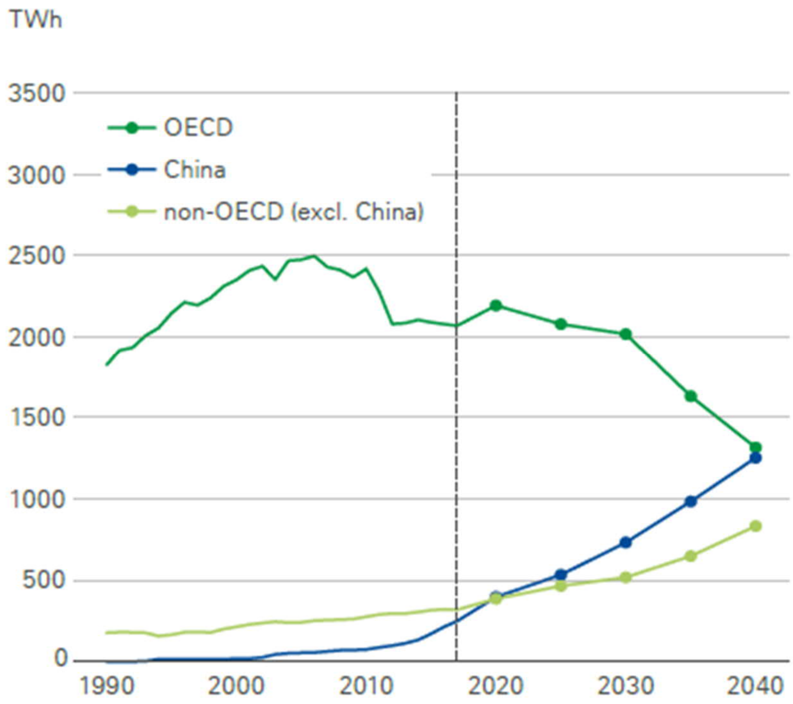

Figure 2.9 – Nuclear energy growth by region. [11]

2.4 Energy Efficiency

Energy efficiency plays a vital role regarding future energy demand and renewable electricity generation. Namely, improvements in energy efficiency will reduce or maintain energy demand despite increases in production levels. Energy savings can be obtained, for example, from buildings, industries, transport, electrical appliances and equipment. Figure 2.10 presents the impact from energy efficiency on electricity generation from renewables. From the figure, it can be noted that the UK's electricity savings from efficiency are nearly as large as the total renewable generation. It can be argued that if these efficiency gains had not been achieved, the energy deficit had been compensated with fossil fuel electricity production. [2, p. 176]

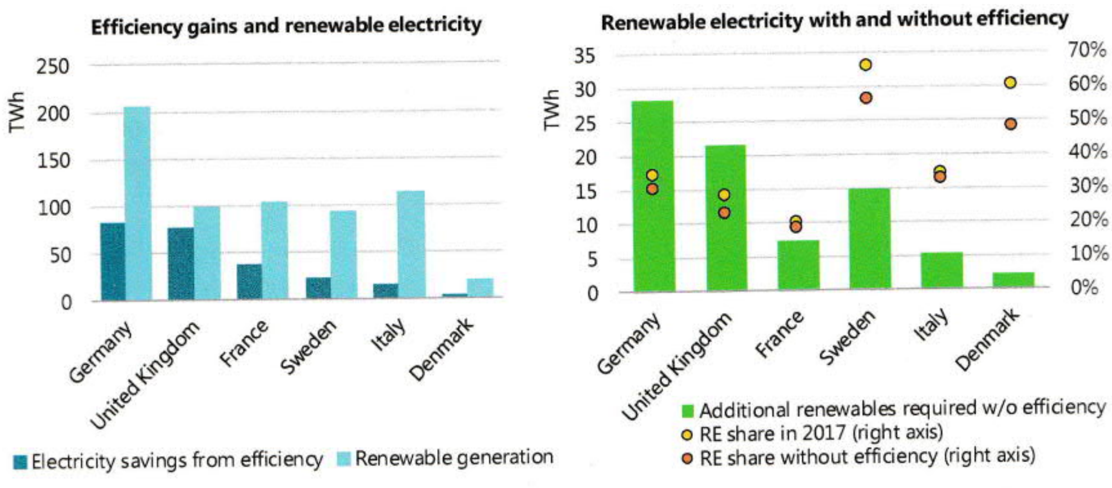

Figure 2.10 – Efficiency gains for renewable electricity targets in Europe, 2017. [2, p. 176]

Another example of the impact of improving efficiency is illustrated in Figure 2.11. In the figure, the total final energy consumption in exajoules (EJ) is considered with the contribution of energy efficiency. Countries included in the figure are Germany, France, the UK, Italy, Denmark and Sweden. It can be seen from the figure that the growth in energy efficiency has been faster than the growth in renewable energy. In terms of policies, it is important to focus not only on renewable energy sources but also on energy efficiency. The EU has set a number of targets to improve efficiency. This is discussed in more detail in Chapter 3. [2, p. 176-177]

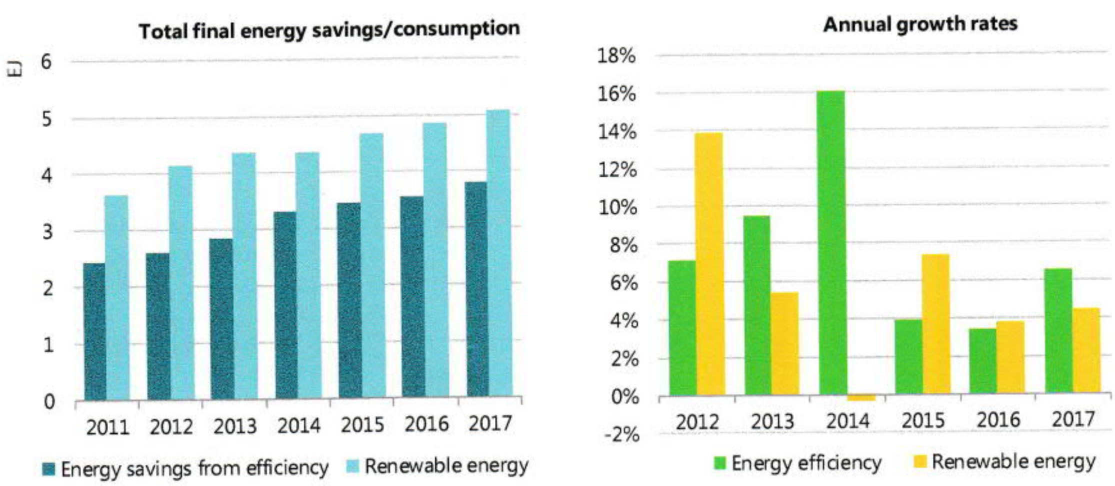

Figure 2.11 – Energy efficiency savings and renewable energy consumption in Europe (EJ). [2, p. 177]

2.5 Grid Integration Concerns

The rise of variable renewable electricity (VRE) generation, such as wind and solar, has steadily increased over the last years. VRE generation fluctuates over time, which in turn, has affected the power system flexibility and poses increasing operational challenges in demand side management. Traditionally, electricity generation from fossil fuels can be steered accordingly by demand and supply. However, by the integration of large shares of VRE, the supply and demand side mismatches have increased. In addition, the uncertainty has also increased, that is, the inability to predict electricity demand and supply output. In order to secure the transmission balances, several grid integration investments are needed for storage technology, control mechanisms, curtailment and forecasting. Policy makers can consider several deployment policies in order to improve VRE integration, for instance, offering VRE support payments, the requirement for the installation of remote monitors, proactive network planning and increasing market exposure, just to name a few. [2, p. 169-172]

3 Global Energy Strategies by Region

This Chapter analyses global energy strategies by region. In other words, international treaties and energy directives are presented and analysed. The primary regions in consideration are the EU, United States, China and India.

3.1 Energy and climate politics within EU

The European Union (EU) has had several aims to reach climate friendlier energy politics and enforce energy sustainability within the EU. This chapter discusses the previous energy agreements and policies, such as the energy alignments for the years 2020-2050. The European Commission has set several strategies and goals for their member states in order to decarbonise the industry as well as to set ambitious goals for renewables. It is estimated that drastic changes regarding energy prices are under way. In other words, the prices will be affected by the large need of future energy sector investments, increasing global energy prices, and carbon pricing. Furthermore, electricity grids need to be upgraded, energy efficiency improvements are required, and outdated power plants need to be replaced by more competitive and cleaner energy. Otherwise, energy market competitiveness, supply security and climate objectives will be weakened [12].

3.1.1 2020 Energy Strategy

In 2007, the European Council adopted energy and climate targets for 2020. The central goals of the energy strategy for the member states is to reduce greenhouse gas emissions by at least 20%, 30% if good conditions, increase renewable energy source generation to 20% of the consumption, and to increase energy savings to at least 20%. These objectives were incorporated into the Energy 2020 strategy, the 10-year strategy proposed in 2010, where energy efficiency is one of the key objectives set for 2020. Moreover, each member state must increase their renewable energy share to 10% in the transport sector. The aims of the energy strategy are important, and in order to achieve the goals, several target priorities and actions are proposed. [12][13]

The first priority is to achieve an energy-efficient Europe with four actions. The first action includes investments into energy-efficient and more sustainable buildings and transport. For instance, measures to reduce oil dependence in transport and renovation of public buildings. The second action is to reinforcing industrial competitiveness by making industry more efficient. This can be done by adopting energy-management programmes, such as audits, plans and energy managers in industries. The third action is to reinforce efficiency in energy supply and distribution. In other words, distribution and supply companies should document their customers' energy savings, for example by installing smart meters. Furthermore, a substantial increase high efficiency district heating and cooling as well as cogeneration need to be implemented. The final and fourth action is to benefit from the National Energy Efficiency Action Plans, in other words, to benchmark and to monitor progress of energy efficiency. This can be done by installing measurable objectives and indicators. [12][14]

The second priority is to build a pan-European integrated energy market. This priority also has four actions. The first action's target is to improve the internal energy market through a legislative and regulatory framework. The second action involves a creation of a blueprint for the European infrastructure during 2020-2030. In other words, large-scale production of renewables is required to be integrated in order to guarantee and secure the energy supply. Moreover, several aims to improve the grid for future demand changes are proposed in the action. The third action is to streamline permit procedures and market rules for infrastructure developments. The aim of the action is to streamline permitting schemes as well as to ensure transparency and acceptance regarding of installation projects. Final action of the second priority is to provide the right financing framework for member states regarding projects involving European interests. That is, a methodology is defined in order to analyse the optimum balance between public and private financing. [12][14]

The third priority of the energy strategy is to empower consumers and to achieve the highest level of safety and security. This priority has two actions. First, making energy policy more consumer-friendly. This means that active policy enforcement at European and national level is required to ensure that consumers have access to affordable energy. The action involves measures in order to help consumer to better participate in the energy market. These measures include: development of guidance based on best practice in the are of switching suppliers, improving the implementation and monitoring of the billing and complaint-handling practices and recommendations. This means that consumers should have access to energy with a reasonable price with the ability to switch from their energy supplier to another, and to monitor the energy consumption. Second action of the priority is to continuously improve the safety and security regarding energy production. For example, the safety conditions of oil and gas extraction are reviewed to prevent liability issues, nuclear safety and security is enhanced, and to secure the development and deployment of renewable energy technologies. [12]

The fourth priority is to extend Europe's leadership in energy technology. This involves three actions: implementing the strategic energy technology (SET) plan, launching four large-scale European projects, and ensuring a long term-term technological competitiveness. The SET plan aims to focus on the development and increase the share of low renewable and low-carbon emission technologies by improving the coordination and cooperation among the member states regarding research and financing [15]. The second actions with its four large-scale projects involve the development of smart grids, electricity storage, sustainable biofuel production, and to improve urban and rural energy savings with so-called smart cities. The third action is to ensure future technological competitiveness by supporting research and science regarding low-carbon technologies. This is done by supporting frontier research projects. [12]

The fifth and final priority is to strengthen the external dimension of the EU energy market and it has four actions in order to achieve the goals. The four actions are the following: integrating energy markets and regulatory frameworks with EU neighbours; establishing privileged partnerships with key partners; promoting the global role of the EU for future low-carbon energy; and finally, to promote legal binding nuclear-safety, security and non-proliferation standards globally. In other words, the integration of neighbouring countries into EU's internal energy market is a key aspect of the priority. [12]

3.1.2 2030 Energy Strategy

As the 2020 strategy, the 2030 energy strategy is a ten-year framework for the period between 2020 and 2030 for achieving a more secure and sustainable energy system as well as to meet the 2050 carbon reductions. The central objectives of 2030 energy strategy is to cut 40% of GHG emissions compared to the levels in 1990, increase the share of renewables to 32% of consumption, and to increase energy efficiency by 32.5%. The 2030 framework was admitted in 2014 and aims to continue and follow-up the previous 2020 energy strategy. [16]

The framework also proposes new policies, such as, the new governance system for the period, which is based on national, plans for competitive, secure and sustainable energy. The objective of the new governance system is to improve investor certainty, increase transparency and policy cohesion as well as to progress coordination in the EU [17]. Moreover, a new and a reformed EU emissions trading scheme (ETS) is to be implemented, which is to ensure that market distortion is avoided by increasing the harmonization of policies in the EU as well as to guarantee competitive prices and energy security [16][17].

In short, the ETS is a financial incentive in order to cut GHG emissions, since 2005 EU has set a cap for the total GHG emissions, which a company can emit each year. EU also issues a fixed amount of allowances, which function as the currency in the carbon market, and each company must hold enough allowances to cover their emissions for each year. The allowances can be bought and sold in the carbon market from other companies, if a company neglects to obtain allowances, it can be significantly fined for neglecting the policy. The idea of ETS is to enable a flexible energy infrastructure for decarbonisation by ensuring that emissions are cut, where it costs the least to do so. Each year the emission cap is reduced and fewer allowances are issued to the market, therefore, the total emissions drop over time. Companies also have a financial incentive to cut their emissions or pay other to do so. [17][18]

3.1.3 2050 Energy Strategy

The 2050 energy strategy is a long-term goal for the EU with several actions in order to reduce GHG emissions by 80-95% by 2050 when comparing to 1990s levels [19]. The roadmap of 2050 proposes several challenges with different policy option scenarios on how to reach the ambitious decarbonisation objectives. In total there are seven scenarios, two current trend scenarios and five decarbonisation scenarios. The two current trend scenarios are: Reference scenario, and Current Policy Initiatives (CPI). The decarbonisation scenarios are the following: High Energy Efficiency, Diversified supply technologies, High Renewable energy sources (RES), Delayed Carbon Capture & Storage (CCS), and Low nuclear.

The reference scenario follows current trends and policies with long-term projections on economic development, GHG reductions, and ETS directive. The scenario takes into consideration policies adopted in 2010 and 2020 targets for RES. The CPI scenario is an updated version of the reference scenario, with the addition of the energy efficiency plan and revised energy taxation directive, which are included in the Energy 2020 strategy. Moreover, the effects of the nuclear disaster in Fukushima is included in this scenario. [19]

The high energy efficiency scenario aims with political enforcement to acquire high energy, for instance, by enforcing more strict requirements for new buildings and appliances, increased renovation rates of existing buildings, and by establishing energy savings obligations on energy utilities. This is estimated to decrease the energy demand by 41% in 2050 when compared to the peaks in 2005 and 2006 [19].

The diversified supply technologies consider a scenario, where no technology is preferred, in other words, all energy sources are equal in the market with no additional support for any specific energy source. Moreover, CCS and nuclear power are publicly accepted. In this scenario, GHG reduction is assumed to be done by carbon. [19][20]

The High RES scenario is driven by enhanced support for renewables, which is estimated to have a share of 75% of gross final energy consumption in 2050, and a share of 97% in electricity consumption. The share of renewables in primary energy is estimated to be 60% in this scenario [20].

The delayed CCS resembles the diversified supply technologies scenario, but in this case, the CCS technology is delayed, which results in a high share of nuclear share. The decarbonisation is pushed through carbon taxation rather than technological advancements [19].

The final scenario is the low nuclear scenario, which is similar to the diversified supply technologies scenario. However, in this assumption no new nuclear power plants are built, which leads to a higher share of CCS [19].

To summarise these scenarios and their forecasts, Table 3.1 presents the projected fuel shares in primary energy consumption for the current trend scenarios and decarbonisation scenarios for 2030 and 2050. From the table it can be noted that in best case, the RES will have 59.6 % share of the primary energy consumption, this is forecasted for the decarbonisation scenarios. In worst case, the RES share could be only 19.9%, which is possible for the current trend scenarios.

Table 3.1 – Fuel shares in primary energy consumption. [20]

		Reference/CPI		Decarbonisation scenarios	
	2005	2030	2050	2030	2050
RES	6,8%	18,4%-19,3%	19,9% - 23,3%	21,9% - 25,6%	40,8% - 59,6%
Nuclear	14,1%	12.1% - 14,3%	13,5% - 16,7%	8.4% - 13,2%	2,6% - 17,5%
Gas	24,4%	22,2% - 22,7%	20,4% - 21,9%	23,4% - 25,2%	18,6% - 25,9%
Oil	37,1%	32,8% - 34,1%	31,8% - 32,0%	33,4% - 34,4%	14,1% - 15,5%
Solid fuels	17,5%	12,0% -12,4%	9,4% - 11,4%	7,2% - 9,1%	2,1% - 10,2%

In Figure 3.1, the energy mix for the total primary energy consumption by fuel in 2050 is illustrated in million tonnes of oil equivalent (Mtoe). The scenarios are modelled according to the input for the 2050 Low Carbon Economy Roadmap. From the figure it can be noted that the primary energy demand is reduced significantly in 2050 compared to 2005. This difference is explained by technological advancements regard energy efficiency on the demand and supply side rather that reduced GDP or sectoral production levels. In other words, in the future it is projected that energy savings will accumulate from more efficient buildings, appliances, heating systems, vehicles, and from electrification in transport and heating [20].

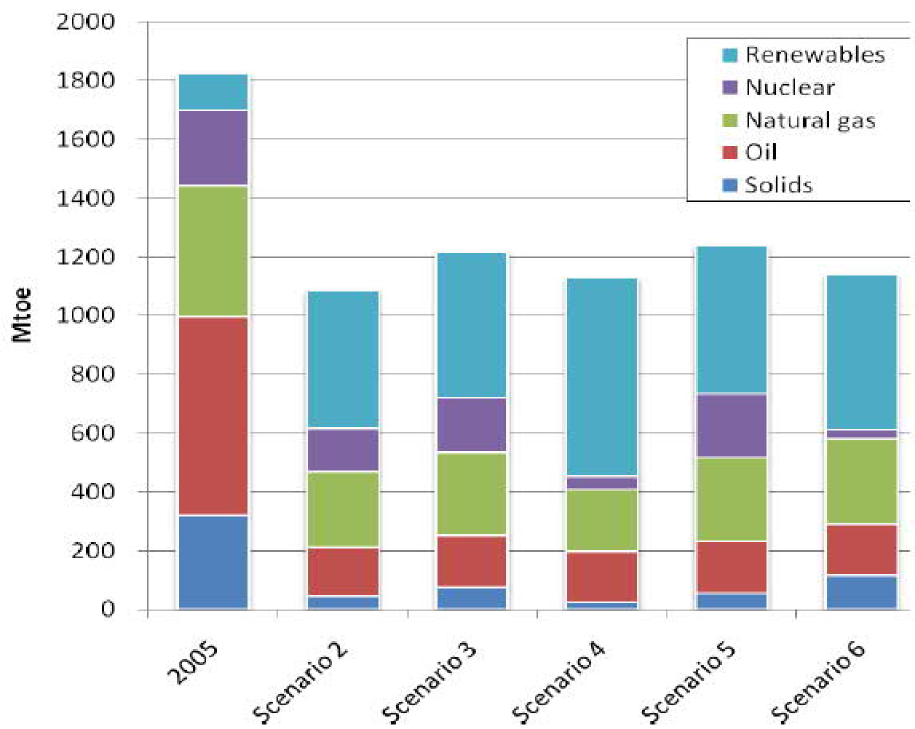

Figure 3.1 – Total primary energy consumption in 2050, by fuel (Mtoe). [20]

3.2 Energy Strategies in the US

This subchapter discusses the energy policies and acts done by the US government. Over the years, the US congress has enacted several statutes, for instance, the Nuclear Waste Policy Act in 1982, and Energy Policy Acts in 1992 and 2005. The US has a significant role in the world energy sustainability, since it has the potential to be in a key role for the transition to renewable energy sources due to its vast opportunities and resources in solar, wind, geothermal, hydro and biomass. Furthermore, the US has financial capabilities, workforce expertise, as well as an agile and entrepreneurial business sector. Moreover, the US energy consumption and GHG emissions are one the largest in the world by country. In 2015, the US. consumed the second most energy in the world, consuming approximately 1 500 Mtoe [3, p. 43]. Therefore, the actions and decisions of the United States have a significant impact on the whole world. The United States energy acts on a federal government, state and a local government level. The United States Department of Energy regulates the law at a federal level, therefore, making it responsible for the energy policies and safety regarding the handling of nuclear material and waste.

3.2.1 Energy Act 2005

The Energy Act 2005 is a bill, which was passed by congress in 2005 and signed into law the same year. The act describes several policy changes, for instance, tax incentives for energy conservation and production, tax breaks for energy and oil industries, and tax credits for individuals who improve their existing homes energy efficiency just to name a few. In other words, the bill proposes several provisions for energy efficiency and tax incentives in order to reduce the energy consumption and promote the use of renewable energies. However, the efforts of increasing renewables, the bill itself does nothing to decrease the oil dependency in the US, and take no impactful actions related to passenger vehicle fuel economy. Moreover, the is also heavily weighted on other traditional energies, such as, natural gas, coal and nuclear power. Of the total \$14.5 billion tax package, renewables and energy efficiency had a share of approximately \$4.5 billion, while the largest share went into nuclear, coal and other fossil fuel production. [21]

3.2.2 Energy Independence and Security Act of 2007

Just two years after the Energy act 2005 was followed-up by another legislation, namely, the Energy Independence and Security Act of 2007. The primary purpose of this energy act was to move US in the direction of energy independence and security, to increase the production of renewable energy sources, to decrease GHG emissions and deploy carbon capture storages, to improve the efficiency of appliances, vehicles, buildings and products, and to protect customers in the energy market [22]. The legislation was divided into several titles and subtitles to address each individual policy in different energy areas. The highlights of the bill can be summarized in the following key provisions which are presented below [23]:

- Renewable Fuels Standard (RFS)
- Energy Efficiency Equipment Standards
- Corporate Average Fuel Economy (CAFE)

The RFS sets a standard, which concludes that an applicable volume of renewable fuels, advanced biofuel, cellulosic biofuel and biomass-based diesel are introduced or sold into commerce in the US on annual average basis for the period 2006-2022. Table 3.2 presents the projected applicable volume of renewable fuel [22]:

Table 3.2 – Volume of renewable fuel for 2006-2022 (billions of gallons). [22]

"Calendar year:	Applicable volume of renewable fuel (in billions of gallons):
2006	4.0
2007	4.7
2008	9.0
2009	11.1
2010	12.95
2011	13.95
2012	15.2
2013	16.55
2014	18.15
2015	20.5
2016	22.25
2017	24.0
2018	26.0
2019	28.0
2020	30.0
2021	33.0
2022	36.0

Energy efficiency equipment standards, that is, the law sets standards for a variety of diverse types of appliances, consumer electronic products and lighting. This includes, for instance, incandescent lamps, fluorescent lamps, dishwashers, refrigerators, freezers, electric motors, clothes washers, and external power supplies just to name a few. [22][23]

CAFE sets a standard for passenger and non-passenger automobiles, as well as for work trucks, medium-duty and heavy-duty vehicles. For example, the standard includes a target of a combined fuel economy standard of 35 miles per gallon for years 2011 through 2020 for passenger and non-passenger automobiles. [22][23]

The final bill excluded two important provisions, namely, Renewable Energy Portfolio Standard (REPS) and Energy Tax Subsidies. The REPS would have enforced retail electricity suppliers to provide a minimum amount of produced electricity from renewables or purchase tradable credits, which represent a same amount of renewable energy production. The energy tax subsidies would have repealed several provisions of oil and gas subsidies of the previous energy act in 2005. Approximately $22 billion of oil and gas subsidies were not repealed in the final bill. [22][23]

3.2.3 Key Notes and Projections to 2050

Despite the withdrawal from the Paris Agreement in 2017 by the US, it is projected that USA will have third-largest capacity growth in the renewable electricity forecast [2, p. 15]. The projected cumulative renewable capacity is expected to increase by 50%, that is, by 132 GW during 2019-2024 [2, p.36]. The driving factors for this change can be explained by better federal tax credits, state-level renewable portfolio standards and incentives for distributed PV, more corporate power purchase agreements (PPA), and declining investment costs for wind and PV [2, p.37].

The investments in renewables done by the US seem promising regarding decarbonisation. One example of this is the 100 by 50 Act, a bill introduced in the Senate in 2017, to transition away from fossil fuel sources of energy to 100% renewables by 2050 [24]. Although the bill has not become law, it is an example of political opinion transition to clean and sustainable energy by 2050. The US Energy Information Administration expects that renewables in the electricity generation mix to year 2050 will have the fastest growth [25]. In addition, electricity generation from coal-fired power plants and nuclear power is projected to decline, which is expected to occur mostly in the mid-2020s. Figure 3.3 illustrates how the forecast for electricity generation will change in 2010-2050. From the graph it can be seen that both natural gas and renewables will truly penetrate the energy market after 2020, while nuclear and coal electricity production will saturate by 2025.

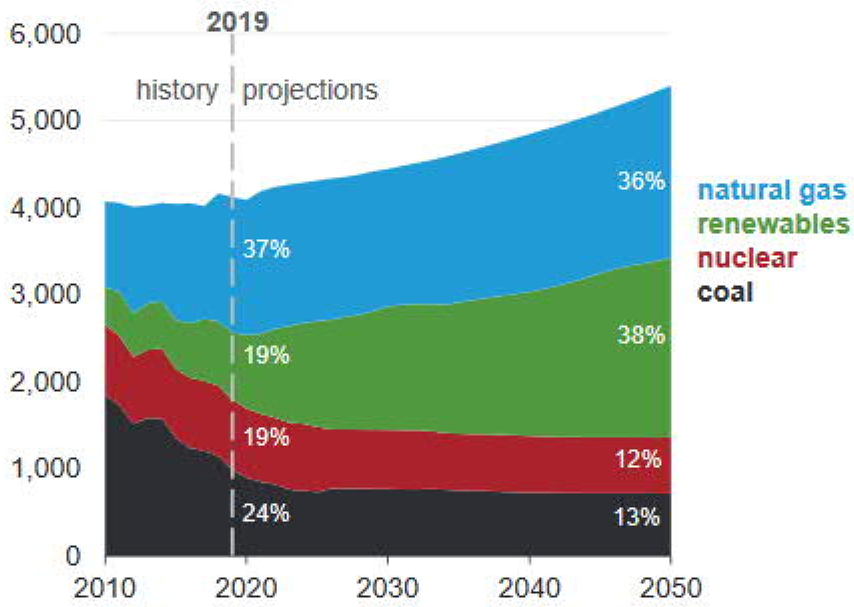

Figure 3.3 – Electricity generation projection for USA (billion kWh). [25]

3.3 Energy Strategies in other Countries

3.2.4 China

China's rapid industrialization and urbanization have made it the world's largest energy consumer. In 2015, China consumed approximately 1800 Mtoe [3, p.42]. The primary energy source for China has been coal, namely, 67% of the primary energy consumption and 73% electricity generation came from coal [26]. In consequence, this has made China the largest emitter of pollutants and GHG emissions. On the other hand, China is the leading country regarding renewables expansion, namely, increasing its capacity with 489 GW during 2019-2024 mostly by wind and PV investments [2, p. 15]. This is explained by the transition from feed-in tariffs (FIT) to competitive auctions, which are expected to make solar and wind better alternatives compared to coal [2, p. 15]. In 2014, China announced that it will increase its renewable share to 20% of all energy by 2030 as well as to peak its emissions by then [26]. Figure 3.2 and 3.3 depict the fast-growing production regarding for solar and wind between 2005-2015 respectively.

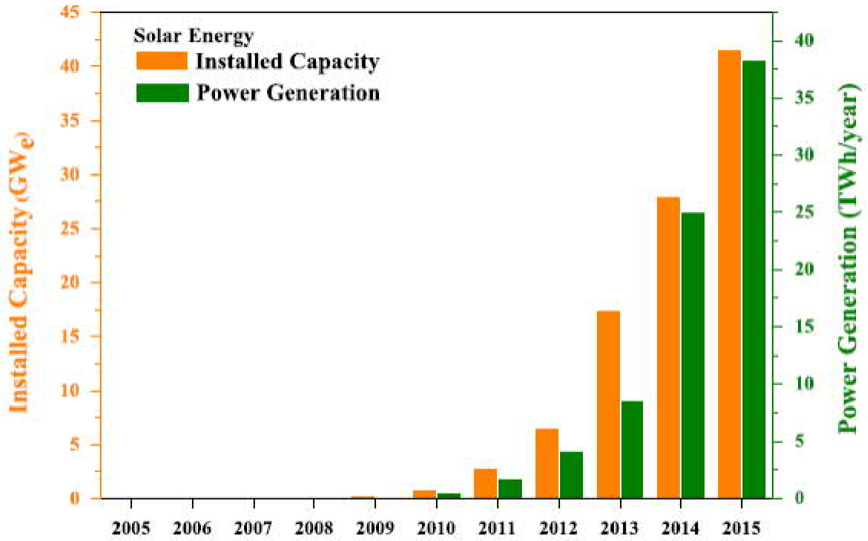

Figure 3.2 – Solar energy growth in China between 2005 and 2015. [26]

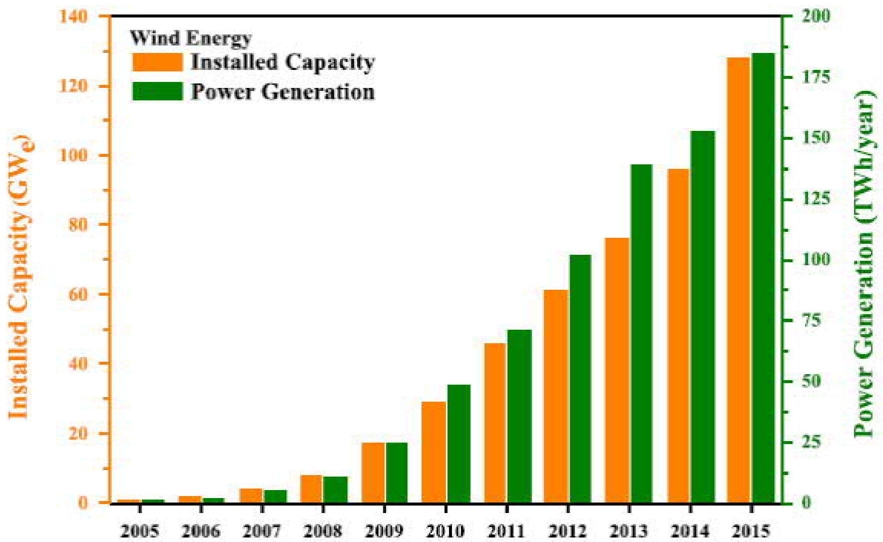

Figure 3.3 – Wind energy growth in China between 2005 and 2015. [26]

China's plans to increase its energy mix is not only limited to renewables, in other words, nuclear energy capacity is expected to be between 150 GWe and 500 GWe in 2050 [27]. Moreover, nuclear power is expected to be 15% of the total electricity production by 2030 and 22% by 2050 [27]. Figure 3.4 illustrates the development of China's electricity generation by fuel for the years 2012-2040.

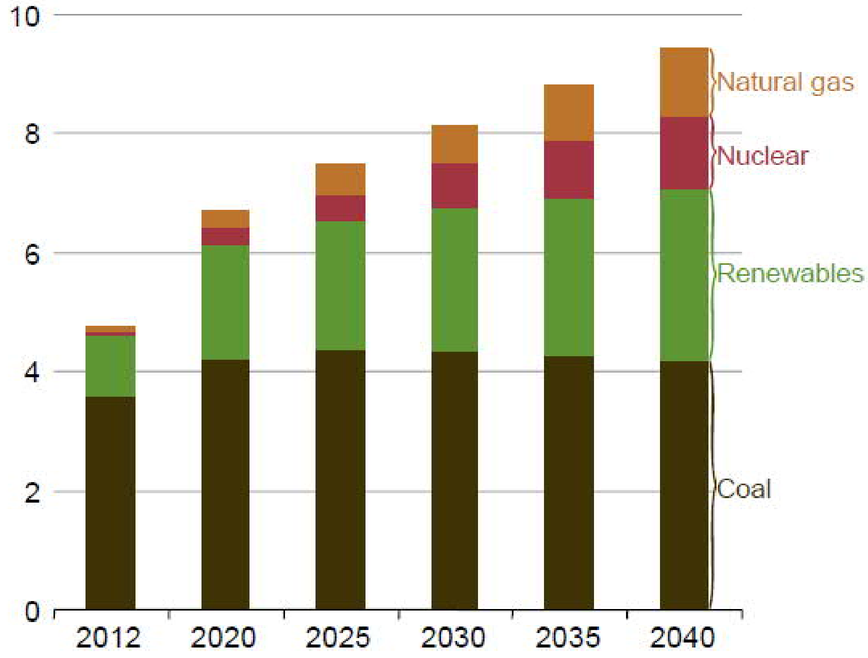

Figure 3.4 – China's electricity generation by fuel source between 2012-2040 (trillion kilowatthours). [28]

3.2.5 India

India has the third highest energy consumption in the world and its energy is heavily dependent on coal-fired power plants, with nearly 70% of total power generation [29]. Furthermore, India is the third largest contributor to GHG emissions and India is only voluntarily committed to carbon reduction targets [29]. On the other hand, its renewable capacity is expected to double between 2019-2024 by 112 GW [2, p. 30]. The increase can be explained by its government's plans to achieve capacity targets of 175 GW by 2022 and 275 GW by 2027 [2, p. 30]. The driving factor for pushing renewables can be explained by India's high electricity demand growth, low bid prices for renewables, and its ambitious targets combined with national and state support schemes [2, p.32]. Figure 3.5 illustrates the projections for India's electricity generation by fuel source for 2012-2040. From the figure, it can be noted that coal will continue to be the largest source of energy consumption. However, the forecast also predicts that renewables are making a slight penetration in the Indian energy mix.

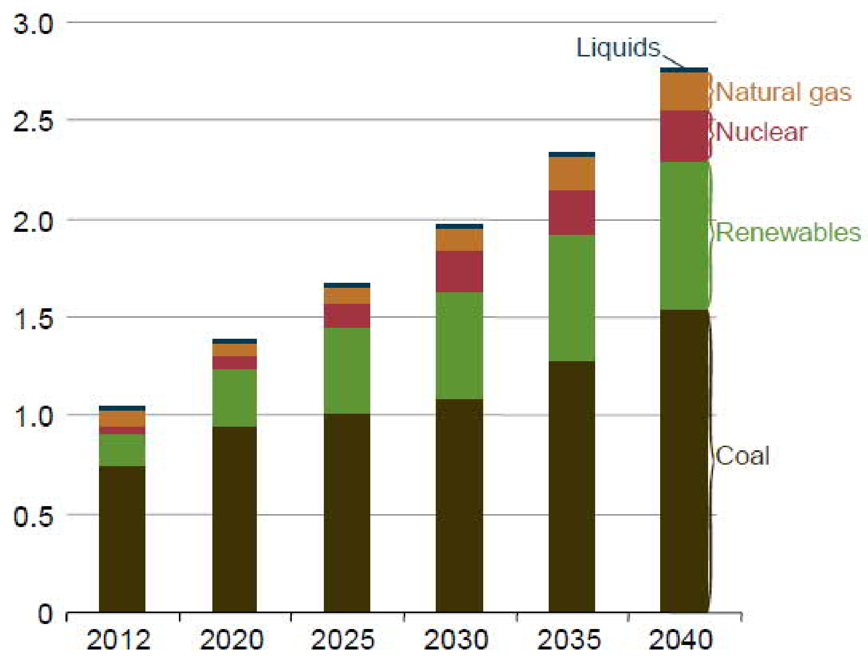

Figure 3.5 – India's electricity generation by fuel source between 2012-2040 (trillion kilowatthours). [28]

4 Energy Trends in 2050

In this Chapter, the energy trends toward 2050 are presented from various literature and analysed. First, the fossil fuel trends for 2050 are discussed. Second, the renewable energy development growth is presented. Finally, a comparison analysis of literature is analysed in order get a full perspective of the energy trends. As with Chapter 2, the WEO provides valuable data and scenarios for predicting the energy development trends, which will be used in this Chapter for analysis.

4.1 Fossil Fuel Trends to 2050

WEO presents three different scenarios for fossil fuel trends toward 2050. The different scenarios are described in the following way [4, p.33]:

- The Current Policies Scenario only takes account of policies that were enacted as of mid-2014.
- The New Policies Scenario – the central scenario in WEO-2014 – describes a pathway for energy markets based on the continuation of existing policies and measures as well as the implementation (albeit cautiously) of policy proposals, even if they are yet to be formally adopted.
- The 450 Scenario illustrates what it would take to achieve an energy trajectory consistent with limiting the long-term increase in average global temperature to 2 °C.

In Figure 4.1, the natural gas demand with different policy scenarios are illustrated. From the figure it can be noted that with current policies, the world natural gas demand will rise steeply towards 6 000 bcm by 2040. However, with new policy improvements, the natural gas demand curve will not be as steep as the previous one, but the difference in demand is small between the two. The most promising results offer the 450 scenario, where the gas demand saturates a bit over 4 000 bcm by 2025. Small fluctuations are still seen in the curve.

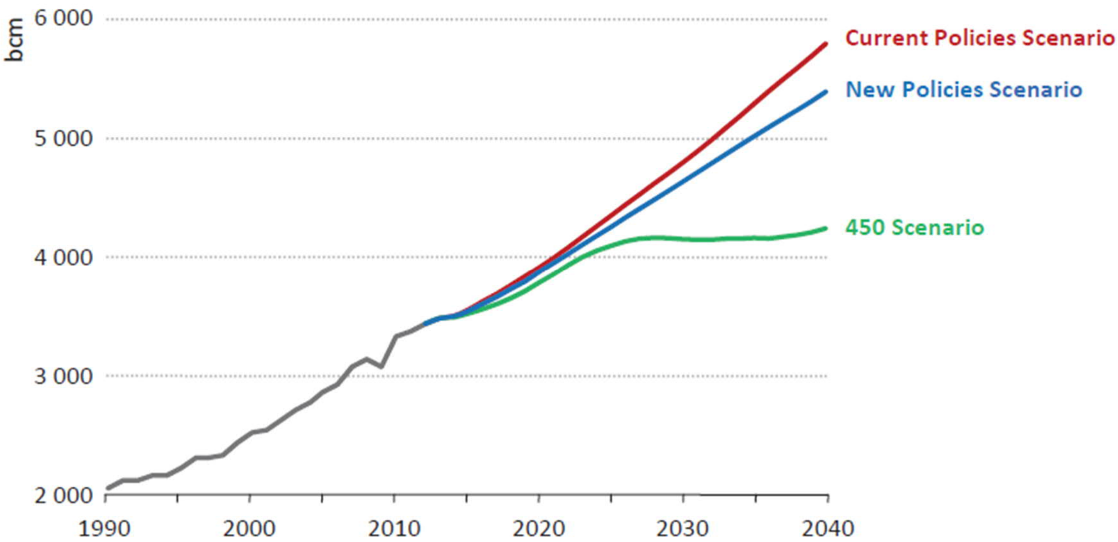

Figure 4.1 – World natural gas demand scenarios in billion cubic metres (bcm). [4, p. 137]

As with natural gas, coal use is heavily dependable on the different policy scenarios. Table 4.1 represents coal demand, production and trade data with the three different scenarios. From the table, it can be seen that 450 scenario shows promising reductions in coal usage. For instance, the worldwide production from 2020 will drop to 3 700 from 5 600 Mtoe by 2040. However, fewer promising results are shown for the two different scenarios, namely, with current policies coal demand production will rise with approximately 2 000 Mtoe. Whereas, new policy changes will keep the coal production and demand at roughly 6 000 Mtoe. What is also noteworthy from the table, is that OECD countries' demand for 450 scenario drops dramatically by the year 2040, only to 608 Mtoe. This can partly be explained by improvements in energy efficiency.

Table 4.1 – Coal demand, production and trade by scenario (Mtoe). [4, p. 174]

				New Policies		Current Policies		450 Scenario	
		1990	2012	2020	2040	2020	2040	2020	2040
OECD	Demand	1 543	1 457	1 378	931	1 475	1 486	1 224	608
	Production	1 533	1 361	1 344	1 172	1 458	1 697	1 195	696
Non-OECD	Demand	1 643	4 084	4 637	5 424	4 892	6 885	4 376	3 092
	Production	1 661	4 306	4 671	5 182	4 909	6 674	4 405	3 004
World	Demand	3 186	5 541	6 015	6 354	6 367	8 371	5 600	3 700
	Steam coal	2 244	4 347	4 757	5 280	5 076	7 098	4 413	2 907
	Coking coal	542	885	950	850	979	965	924	705
	Lignite	400	309	309	225	312	308	263	88
	Production	3 194	5 667	6 015	6 354	6 367	8 371	5 600	3 700
	Inter-regional trade*	309	1 022	1 187	1 432	1 279	1 856	1 062	594
	Steam coal	162	759	899	1 101	966	1 472	792	354
	Coking coal	186	268	296	336	321	390	279	247

Figure 4.2 illustrates the world oil demand in millions of barrels per day (mb/d) and oil price for the three different. From the figure, oil demand will drop drastically in the 450 scenario and oil price staying nearly the same over the years. However, with current policies, oil demand and price will rise steeply towards 2040. In the new policy scenario, the oil demand saturates at approximately 105 mb/d, while oil price is seen to have a slight increase over the years.

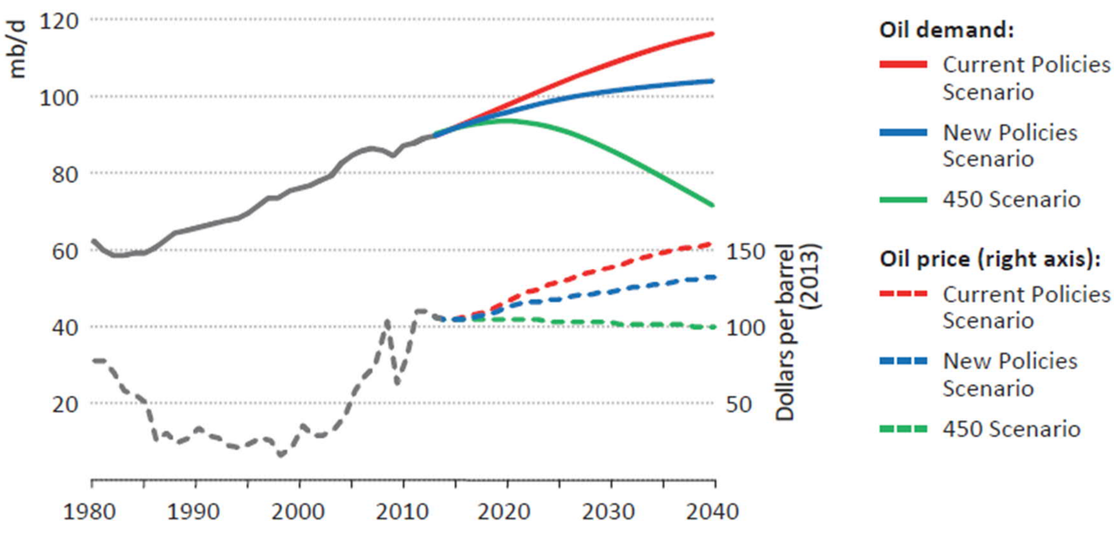

Figure 4.2 – World oil demand and oil price by scenario. [4, p. 97]

Nuclear energy outlook also plays a vital role in the future energy mix, which must be considered. In Figure 4.3 the global nuclear power capacity by scenario and case are depicted. Notice that there are two more trend lines, namely a High Nuclear Case and a Low Nuclear Case. The high scenario is an optimistic case, while the low nuclear case is based on plausible assumptions that could materialise. In the High Nuclear Case, an installed nuclear capacity of 767 GW is achieved in 2040 [4, p. 403].

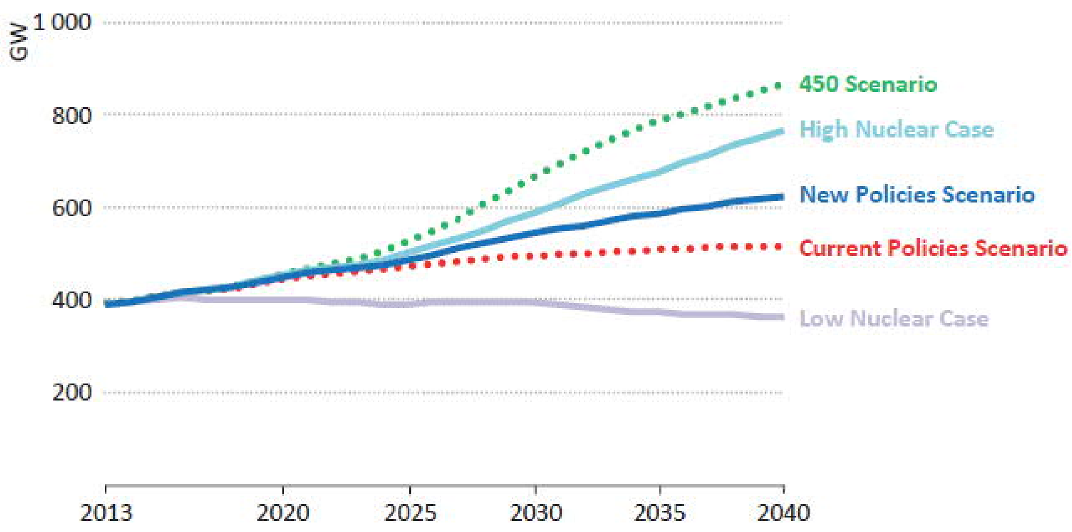

Figure 4.3 – Global nuclear power capacity by scenario and case (GW). [4, p.406]

Further analysis of nuclear power scenarios by region is presented in Figure 4.4, where it can be seen that in OECD countries the capacity changes are more moderate compared to non-OECD countries. In Non-OECD countries, all scenarios have steep trend lines regarding nuclear power capacity increase. On the other hand, nuclear capacity increase in OECD countries is heavily dependent on the scenario. Note that HNC = High Nuclear case; NPS = New Policies Scenario; and LNC = Low Nuclear Case.

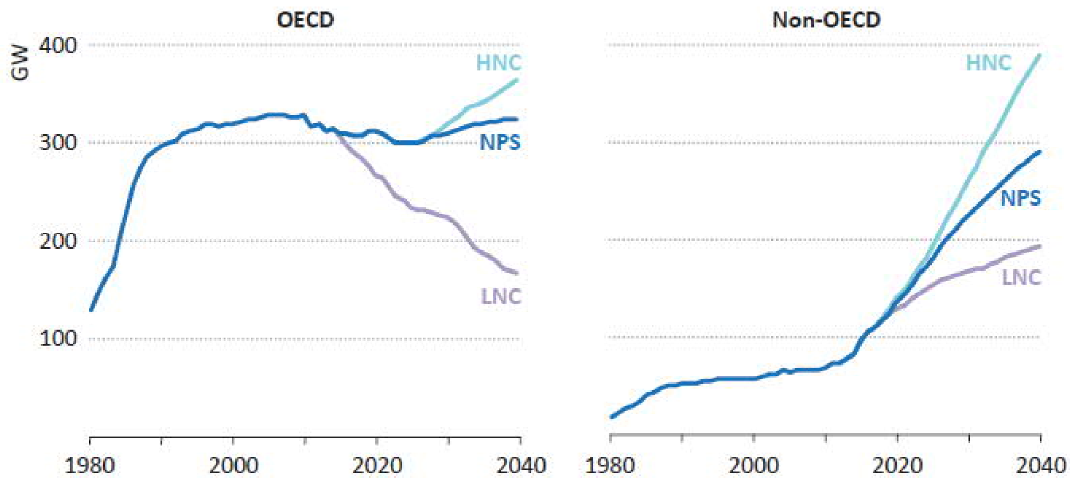

Figure 4.4 – Nuclear power capacity by region, by scenario and case (GW). [4, p.405]

4.2 Renewable Energy Trends to 2050

As with fossil fuel analysis, renewable energy trends will be analysed with the same scenarios as described in Chapter 4.1. Table 4.2 represents the data for the different scenarios, from which it can be noted that renewable shares will rise in each scenario, regardless what policies are implemented. However, the 450 scenario has a dramatic rise in renewables compared to the others. For instance, the EU renewable demand will almost double from 2020 to 2040, whereas, the US will almost increase its demand by threefold.

Table 4.2 – World renewables consumption by scenario. [4, p. 242]

		New Policies		Current Policies		450 Scenario	
	2012	2020	2040	2020	2040	2020	2040
Primary demand (Mtoe)	1 802	2 254	3 455	2 223	3 095	2 276	4 658
United States	136	186	346	181	290	188	555
European Union	198	263	390	255	351	267	504
China	316	410	589	397	501	414	842
Share of global TPED	*13%*	*15%*	*19%*	*15%*	*15%*	*16%*	*30%*
Electricity generation (TWh)	4 807	7 263	13 229	7 010	11 046	7 329	17 973
Bioenergy	442	764	1 569	740	1 299	768	2 261
Hydro	3 672	4 553	6 222	4 458	5 862	4 561	6 943
Wind	521	1 333	3 345	1 254	2 552	1 376	4 953
Geothermal	70	120	378	113	287	121	557
Solar PV	97	449	1 291	408	832	459	1 982
Concentrating solar power	5	41	357	34	173	42	1 158
Marine	1	3	66	3	41	3	119
Share of total generation	*21%*	*26%*	*33%*	*25%*	*25%*	*27%*	*51%*
Heat (Mtoe)*	345	431	716	431	670	450	932
Industry	198	242	367	246	381	249	447
Buildings* and agriculture	147	189	348	185	289	201	485
*Share of total final demand**	*10%*	*11%*	*16%*	*11%*	*14%*	*12%*	*23%*
Biofuels (mboe/d)**	1.3	2.2	4.6	1.8	3.6	2.1	8.7
Road transport	1.3	2.2	4.5	1.8	3.6	2.1	7.2
Aviation***	-	-	0.0	-	0.0	-	1.5
Share of total transport fuels	*2%*	*4%*	*6%*	*3%*	*5%*	*4%*	*20%*
Traditional use of solid biomass (Mtoe)	758	755	648	760	671	750	633
Share of total bioenergy	*56%*	*49%*	*32%*	*49%*	*35%*	*48%*	*25%*
Share of renewable energy use	*42%*	*34%*	*19%*	*34%*	*22%*	*33%*	*14%*

Renewable-based electricity production also provides CO_2 emission reductions. Figure 4.5 depicts the amount of emissions which can be avoided by using renewables concerning the New Policies Scenario.

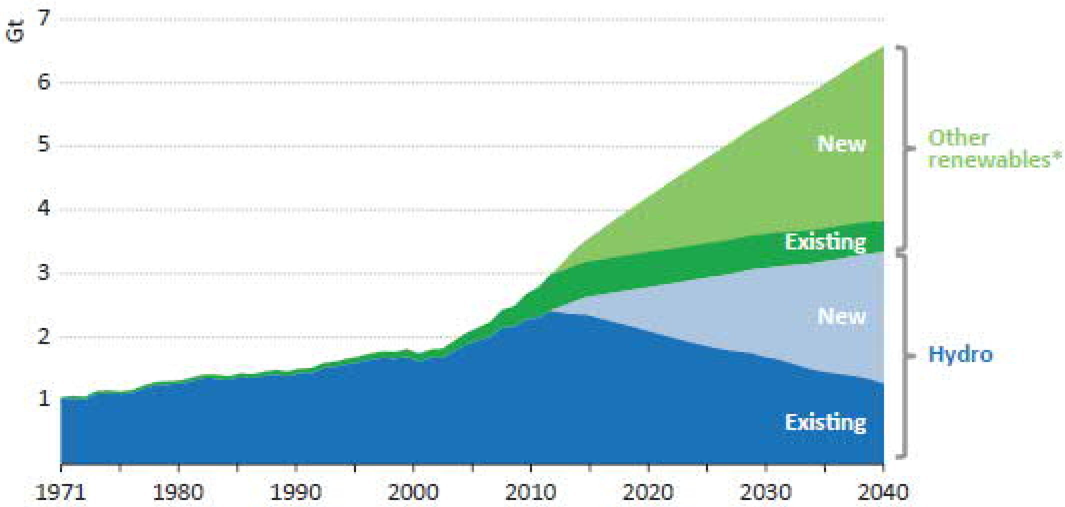

Figure 4.5 – Worldwide CO_2 emissions avoided using renewables in the New Policy Scenario. [4, p. 256]

4.3 Comparison with Other Literature

Comparing WEO's scenario analysis in previous subchapter with other literature we can establish a better understanding regarding the future energy outlook. Figure 4.6 illustrates the fuel shares in power for coal, hydro & nuclear, gas and renewables. From the figure it can be seen that same trends can be spotted as with previous subchapter's figures. Namely, Renewables have a high penetration, while coal is going to decrease rapidly. Nuclear and gas will have insignificant changes over the years in comparison to the other energy resources.

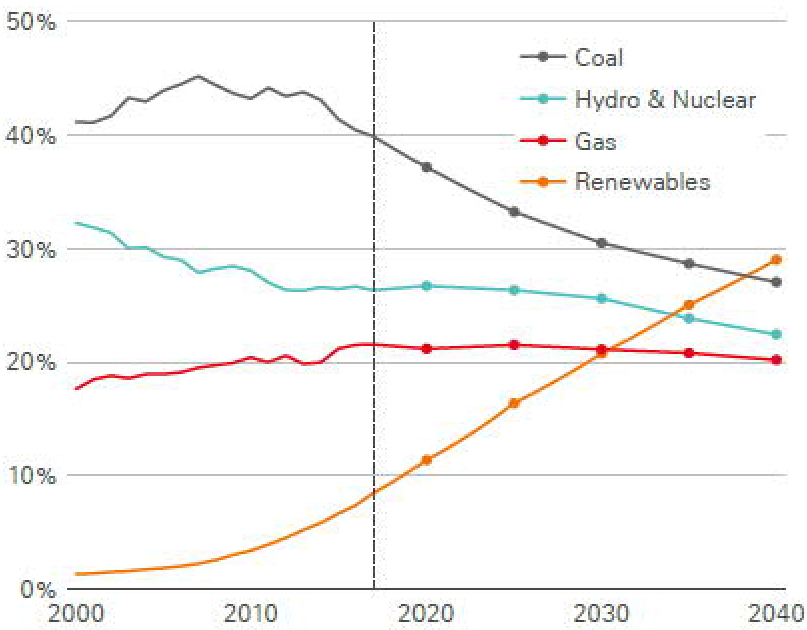

Figure 4.6 – Fuel shares in power between 2000-2040. [19]

In Chapter 3, the energy strategies for the EU, the US, China and India were discussed. The primary energy consumption and energy mix for these countries are presented in Figure 4.7. From the figure, it can be noted that coal will still be the primary energy resource for China and India, whereas the EU and the US will decrease its usage. This is in line with the strategies, which were discussed in Chapter 3.

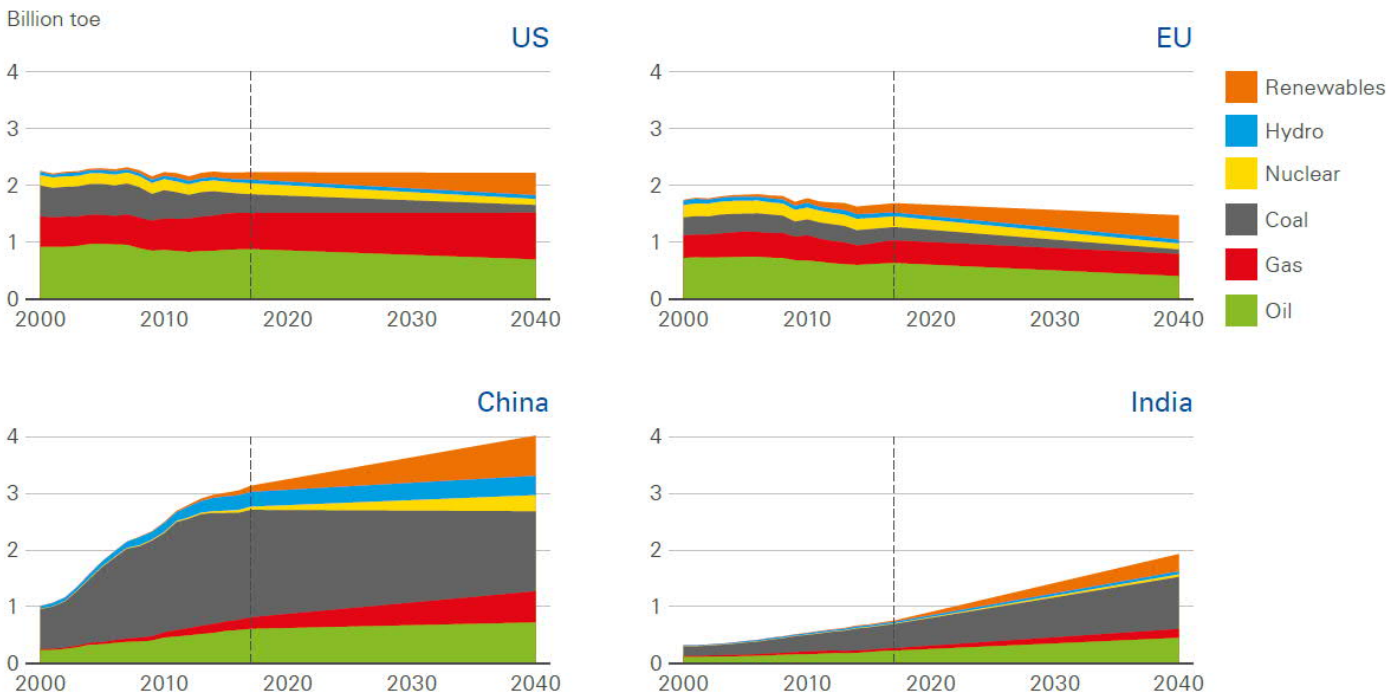

Figure 4.7 – Energy mix for the EU, the US, China and India between 2000-2040. [19]

Comparing nuclear energy development presented in Figure 4.4 with the Figure 4.8, we can see that same trends are projected for OECD and non-OECD countries. Namely, there is a large growth in capacity regarding non-OECD countries. Furthermore, OECD countries capacity growth seems to drop, this is in line somewhere between New Policies Scenario and Low Nuclear Case.

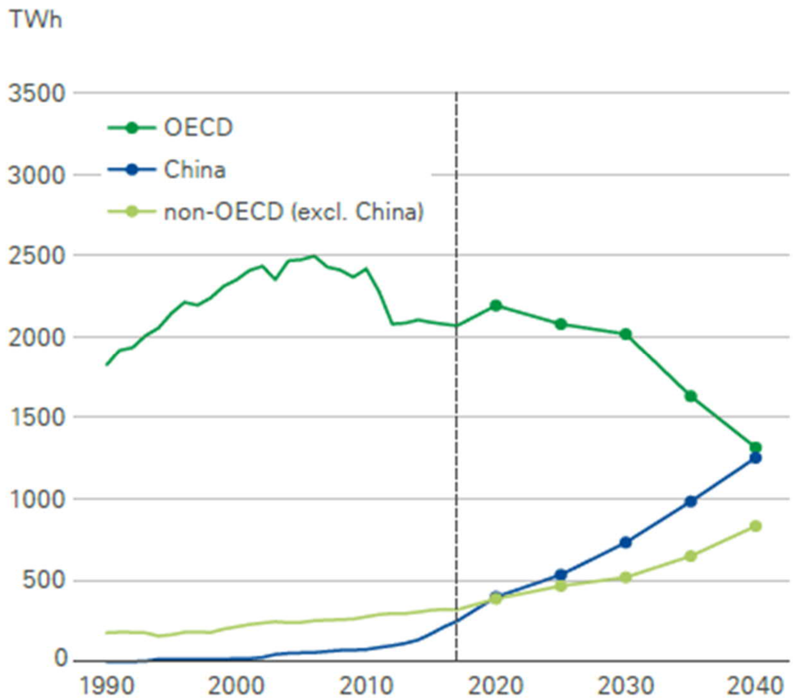

Figure 4.8 – Nuclear energy growth by region. [11]

Finally, we will compare the two other literature with a third regarding the total world energy consumption. Figure 4.9 illustrates the world energy consumption by energy source is measured in quadrillion British thermal units (Btu). From the figure, we notice that renewables once again have high penetration in the energy mix, which is in line with the two previous literature presented in this chapter. Nuclear energy capacity has a small increase, which is in line with High Nuclear Scenario in and New Policies Scenario presented in Figure 4.3. In addition, natural gas increase is in line with Figure 4.6. Moreover, Current Policies Scenario and New Policies Scenario in Figure 4.2 is showing same trend as liquid fuels in Figure 4.9.

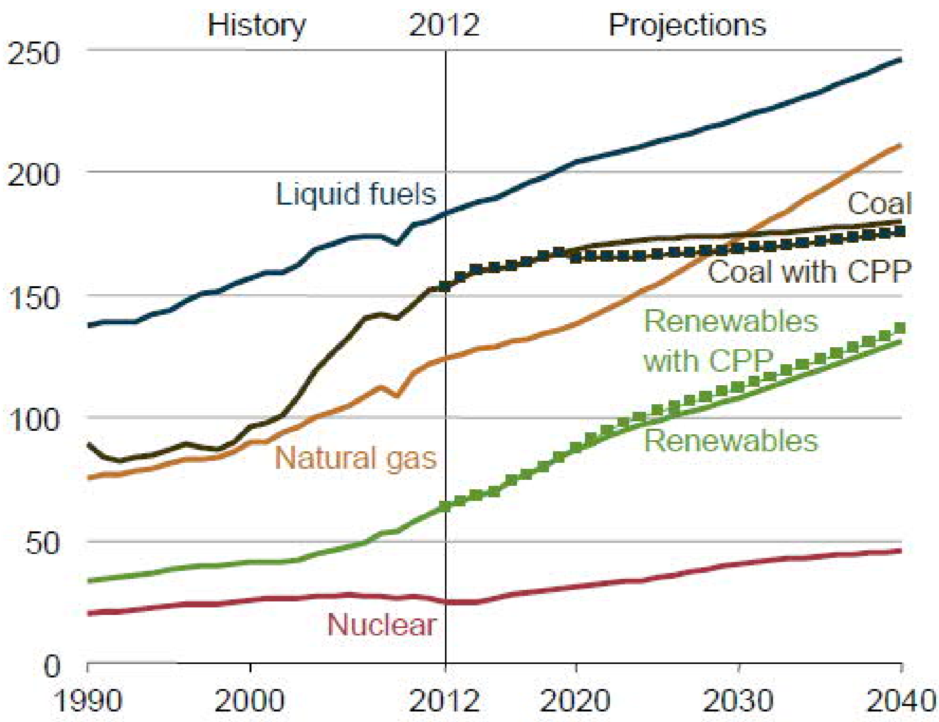

Figure 4.9 – Total world energy consumption by energy source 1990-2040 (quadrillion Btu). [28]

5 Conclusions

In this thesis, the recent energy trends were discussed in Chapter 2, from which it can be noted that renewable energy is increasing in a global scale. Fossil fuels are still a primary energy resource worldwide, however, a slow trend is seen in phase-outing fossil fuels plants and compensating them with renewables. The leading regions and countries regarding renewable energy expansions are the EU, USA, China and India. Currently, hydropower is still leading the primary source of renewables. However, solar and wind energy are rapidly deployed and adapted in various countries, thanks to decreasing investment costs and better technological advancements. In addition, the importance of energy storage, improvements regarding energy efficiency gains as well as the effects of variable renewable sources on power system flexibility were briefly discussed.

Chapter 3 discussed different regional strategies regarding energy strategies. The EU has made several aims to decarbonise its industrial sector, for instance, the 2020, 2030 and 2050 strategies and plans are made to ensure that the renewable energy targets, energy efficiency improvements and GHG emissions reductions are achieved. The United States has experienced a bit of a setback in its GHG reduction process, namely the withdrawal from the Paris Agreement in 2017 has caused political conflicts and slowed down its decarbonisation targets. On the other hand, USA is still expected to have the third-largest capacity growth in the renewable electricity forecast. China, the largest energy consumer and emitter in the world, is steadily increasing its shares of renewables as well nuclear energy. Currently, driven mostly by coal-fired power plants, China has set ambitious goals for its renewable targets in the coming years. Namely, an expansion of 489 GW over 2019-2024. Finally, India's role and its goals were discussed. For example, its plans to double the shares of renewables by between 2019-2024.

Chapter 4 presented various energy trends and energy sector developments. WEO's scenario analysis was used for review. In which, three different scenarios were presented and analysed. The scenarios were divided into a Current Policy Scenario, New Policy Scenario and 450 Scenario, which took into account what it would take to achieve an energy trajectory consistent with limiting the long-term increase in average global temperature to 2 °C. From the analysis it can be stated that fossil fuels are still in a central role in the global energy consumption. On the other hand, renewables are seeing a promising potential in the energy mix. The 450 scenario presented an optimal case for renewables, in which renewables had a significant impact on emissions as well as on the decrease of fossil fuel usage. However, the current policy scenario projected large use in fossil fuels and only slight increases in renewables. Finally, the scenarios were compared with other literature, from which it can be stated that the energy outlooks for 2050 are quite similar. Namely, coal use is projected to drop rapidly, renewable energy sources will increase, and nuclear energy will not have significant changes.

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